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## INTERRELATIONS OF THE FOSSIL FUELS.\*

### II.

By JOHN J. STEVENSON.

(Read April 14, 1917.)

#### THE CRETACEOUS COALS.

Coal of Cretaceous age occurs more or less abundantly in many countries. The original areas in which it was formed vary from mere patches to thousands, even hundreds of thousands of square miles; but these greater areas have been broken by erosion into isolated basins, or better into isolated fields, sometimes widely separated. The coal seams are not confined to a single horizon but are present throughout the Cretaceous at localities where proper conditions existed. The several regions have so many features in common as well as so many in contrast that a detailed description of some typical areas, though tedious, is necessary for proper understanding of the relations.

#### EUROPE.

In western Europe, coal is confined almost wholly to the Wealden but in central Europe the Upper Cretaceous contains deposits of more than local importance.

Coal in thin seams has been observed at some places in England but the quantity is significant. The Wealden of the Dorsetshire coast and of the Isle of Wight has no coal. Mantell<sup>1</sup> states that, at Brook Point on the Dorset coast, a sandstone ledge in Lower Wealden encloses trunks and large branches of trees, mostly petrified. Webster, at an earlier date, had seen these stems, of which some had been converted into a jetlike substance. Mantell, observ-

\* Part I. appeared in these *Proceedings*, Vol. LV., pp. 21-203.

<sup>1</sup> G. A. Mantell, "Geological Excursions round the Isle of Wight," 3d ed., London, 1854, pp. 203-206, 238, 239, 242.

ing that all the stems are prostrate, thought them a fossil raft, remains of an ancient pine forest, transported by a river and buried in the delta sands and muds, as is the case with rafts of the Mississippi River. But the description of conditions leads one to hesitate before accepting the reference to rafts. The Mississippi rafts, as described in European works of Mantell's day, were not the rafts as they were. It is not probable that the rafts of the Atchafalaya and Red River would produce deposits such as those under consideration. The features<sup>2</sup> are more like those observed along the Athabasca and some other North American rivers, where great masses of driftwood occur, the interstices being filled with silt and sand. Mantell emphasizes the presence of ripple markings in the Wealden; slabs of sandstone, clay and limestone on the Isle of Wight are often covered with them. Imprints of annelid and molluscan trails, of crustacean claws, of pectoral fins of fish as well as of feet of reptiles have been obtained. The formation is of essentially fresh-water origin. Lyell,<sup>3</sup> in describing the Lower Wealden or Hastings sand, remarks that one finds at different heights in the section strongly rippled slabs of sandstone. Some of the clay beds had been exposed, for sun cracks are abundant. A red sandstone, near Horsham, contains innumerable traces of a plant, apparently *Sphenopteris*, with stems and branches disposed as if they are standing erect on the place of growth, the sand having been deposited gently around them. Similar conditions have been observed elsewhere in this formation.

Some coal has been found in the Wealden of France, but it is of little importance. The lignites of Simerols<sup>4</sup> suffice as illustration. The area is small, with radius of about 25 kilometers. The section at one locality shows (1) clay, 0.90; (2) lignite, 2.50, at times without partings, but at others divided into two or three benches; (3) shale, 0.70; (4) lignite, friable, not mined, 1.50; (5) carbonaceous shale, 0.80; (6) lignite, compact, 1 to 1.50; total, 7.90 meters. This deposit, at times only 4.60 meters thick, underlies

<sup>2</sup> See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., 1911, pp. 548-551.

<sup>3</sup> C. Lyell, "Elements of Geology," 6th ed., New York, 1866, pp. 350, 351.

<sup>4</sup> Arnauld, "Des argiles lignitiferes des Sarladais," *Bull. Soc. Geol. France*, II., Vol. 23, 1866, pp. 59-63; Meugy, the same, pp. 89-96.

marine Cretaceous, but is of fresh-water origin, the animal remains being indeterminate bones with shells of fresh-water mollusks. Plant remains and silicified stems are in the clays. The lignite is described as compact, blackish brown and lusterless.

The Wealden of Hanover, that portion equivalent to the Hastings sand of England, has coal seams, which in many places have economical importance. The region<sup>5</sup> has been studied by several geologists, each having in view the study of some special features. The area has extreme length from east to west of about 160 miles and an extreme width of about 120 miles from north to south. Exposures are not continuous, for erosion has removed the Wealden from extensive spaces, while in others the surface rocks belong to later formations. According to Credner, it reaches from the Harz Mountains westward to the Holland border, where it passes under a thick cover of diluvium. The exposed areas are isolated and at times are so widely separated that sections have little resemblance. The Wealden consists of clays, marls, sandstones and coal beds; the colors are from white to gray, with rare bands colored by oxide of iron. Dunker states that the coal usually resembles the older black coals, the plant materials have undergone much greater change than in brown coal, and distinct woody structure is rarely recognizable. Some mines yield a coal comparable to the best in England; a sample, analyzed by Regnault, gave carbon, 89.50; hydrogen, 4.83; oxygen and nitrogen, 4.67; ash, 1. This type is dense, brilliant, with uneven to conchoidal fracture and in appearance resembles anthracite. It is closely jointed and usually has a blackish brown streak. But there is lignite in the Wealden, with woody structure and reddish brown streak. A sample from Helmstadt, analyzed by Varrentrapp, yielded carbon, 68.57; hydrogen, 4.84; oxygen and nitrogen, 19.87; [ash, 6.72]. Dunker thinks this brown coal derived from conifers, cycads, lycopods and ferns.

In the Osterwalde, a very different type, the Blätterkohle, is

<sup>5</sup> W. Dunker, "Monographie der Norddeutschen Wealdenbildung," Braunschweig, 1846, pp. xi-xxviii, 2, 21; Heinrich Credner, "Ueber die Gliederung der oberen Juraformation und der Wealden-Bildung im nordwestlichen Deutschland," Prag, 1863, pp. ix, 47-54, 132, 138, 133, 138-141; C. Struckmann, "Die Wealden-Bildungen der Umgegend von Hannover," Hannover, 1880, pp. 14-28, 30-36.

found in the same section with other coals, some of them belonging to the "black coal" type. This Blätterkohle consists chiefly of *Abies linki* and *Pterophyllum lyellianum*, whose densely packed leaves and twigs, mostly brown and transparent, become flexible, when soaked in water; coalification is extremely imperfect. Dunker thinks that lycopods and ferns are the chief constituents of the black coals, as no remains of other plants have been discovered. It may be noted in passing that the Blätterkohle bears great resemblance to the conifer peat of the Fichtelgebirge,<sup>6</sup> as described by Reinsch, and to the "coarse" coal of the Carboniferous; in the latter the conversion is complete. It must not be forgotten that David discovered equally flexible remains of plants in the Permo-carboniferous of New South Wales.

The coals vary in quality; partings thicken and at times the whole seam becomes carbonaceous shale; occasionally masses of silicious matter, limestone or pyrite become so abundant as to render the deposit worthless. In some mines, a waxy substance, clear or dark yellow, occurs, which Dunker thinks may be hatchettin.

Near Bückeburg and Schaumburg, the Wealden sandstone is 120 to 150 feet thick and contains 4 coal seams, of which two are workable. On the Osterwalde, the thickness is not far from 450 feet and 18 seams were seen, mostly thin or too poor in quality to justify mining, the greatest total thickness of coal being 9 feet. Well-marked coal seams, in nearly every case, have a black clay roof and floor, the latter occasionally passing into Brandschiefer or cannel shale. The roof clay, at times, contains abundance of plant impressions and even becomes coaly—a true faux-toit. In the upper part of the section there are two seams consisting mostly of the black coal, but this, in part, is continuous with brown coal, containing pieces of wood-like anthracite.

The plants enumerated by Dunker include 2 species of *Equisetum*, 26 of ferns, 10 of cycads, 5 of conifers and one palm, *Endogamites*, now taken to be *Sedgwickia*. One species of *Equisetum* occurs abundantly in a sandstone, where the stems are more or less nearly vertical. Stems of trees were observed at many localities;

<sup>6</sup> See "Interrelations of the Fossil Fuels, I.," *Proc. Amer. Phil. Soc.*, Vol. LV., 1916, p. 54.

those replaced with sandstone or oxide of iron show no trace of structure, but those from the coal resemble *Pinus*. He believes that much of the coal is derived from conifers.

Credner reports that the sandstone is 540 to 550 feet thick on the south slope of the Diester range, 8 to 12 miles south from Hannover, where it consists of alternating clay shales, marly shales, sandstones and stone coal; the chief mass is a yellow, fine-grained sandstone with little cementing material. The section shows 16 coal seams, of which 11 are less than 10 inches thick and have "bad coal." Three beds, 2 feet, 1 foot 6 inches and 1 foot respectively, are of "workable" thickness and yield good coal. Clearly, the periods when coal accumulation was possible, were of brief duration and the general conditions were not such as to encourage formation of good coal; the total thickness is little more than 15 feet, of which less than one third is good. The fauna is fresh-water, *Unio*, *Paludina*, *Cypris*, *Lepidotus* and *Sphaerodus* being the prevailing forms; *Cyrena* is not rare. The flora consists of ferns, cycads, conifers and palms.

The Osterwalde area is farther west; its resources had been developed after Dunker's examinations were made. The Wealden sandstone is approximately 500 feet, but the conditions are not the same as in the Diester area. The "workable" coal seam, one foot thick and 28 feet above the base at Diester, is here in the same position, but only 8 inches thick. Within 72 feet above it are 3 seams, the thickest being 6 feet 9 inches, all absent from the Diester section. Near Minden, 7 miles farther west, the coal is thicker. Meanwhile the character of sediments has been changing, for the sandstone, predominating at Diester, is insignificant here. The change continues westward: at Bentheim and Ochtrup, on the Holland border, one finds only clays and limestones about 800 feet thick; the limestones yield *Melania* and *Cyrena*. According to Credner's descriptions, it is evident that the coal decreases in the direction of finer sediments. The thick coals of Minden are associated with the one noteworthy sandstone of that area. Both Dunker and Credner note abundance of sphaerosiderite in the rocks associated with coal seams.

Studies by Dunker and Credner were mostly in the region west from Hannover; Struckmann gave information respecting other

areas and added to that respecting the western. The coal-bearing deposits equivalent to the Hastings sand are his Middle Wealden; his Lower Wealden is equivalent to the Purbeck beds of England, now placed in the Jurassic. The whole Wealden of Struckmann is only 15 meters thick under the city of Hannover; the Hastings sand is thin but contains an unimportant seam of coal. At Neustadt, 10 miles farther northwest, the sand is still present, though very thin, and holds thin coal, which has been utilized. At 24 miles west-northwest, the sand is insignificant, almost wholly replaced by a thick, often bituminous clay and marly shale, shale, rich in pyrite, but holding some coal.

The Hastings sand increases southwardly. At 10 miles west from Hannover, thick beds of sandstone appear; on the Diester, south from that city, as well as on the Süntel ridge at the southwest, sandstone prevails; but at Osterwalde, sandy and clayey shales are abundant, though there are prominent beds of sandstone. Struckmann compares several sections, I., on the Diester by Credner; II., farther west by himself; III., on Osterwalde by Credner; IV., at Rehburg, northwest from Hannover, by himself:

	I.	II.	III.	IV.
Sandstone. ....	118.63	124.33	47.00	6 to 7
Clays, marls, sandy shale, soft sandstone	40.00	37.62	110.00	114.00
Coal, worthless. ....	2.06	0.87	3.00	0.00
Coal, workable. ....	1.31	0.84	2.50	0.23
Total, meters. ....	162.00	163.66	162.50	120.00

In I., there are 12 worthless seams and three workable; in II., 3 worthless and one workable; in III., 6 worthless and 5 workable; in IV., one workable.<sup>7</sup> In III., sandy shales or very slightly consolidated sandstones, but in IV. clays and marls make the greater part. These observations by Struckmann show that the source of sediment was south from Hannover and that the sand flats decreased toward the west and north, giving place to less coarse materials. The coal seams are irregular and it is evident that many of them are of insignificant lateral extent. Sphærosiderite is abun-

<sup>7</sup> It would appear that in these calculations any seam yielding good coal and more than ten inches thick is thick enough to be mined.

dant. The fauna is fresh-water. The flora at Osterwalde consists of ferns, cycads and conifers, but two forms, an *Anomozamites* and a *Spirangium*, are wanting there, though they are extraordinarily abundant on the Diester.

Hosius<sup>8</sup> discovered plant remains and fragments of coal in the Wealden sandstone near Vreden in Westphalia about 35 miles west-northwest from Munster.

The Upper Cretaceous is almost wholly marine in England, France and western Germany, so that coal occurs rarely and in small quantity; but farther east, in Saxony, Bohemia, Silesia and Moravia, the limestones and marls are replaced with sandstones at several horizons and coal deposits are present, which in some areas have much economic importance.

The Löwenberg basin in southern Silesia is at about 25 miles from the border of Saxony and Bohemia. According to Scupin,<sup>9</sup> the coal of this basin has been regarded as either stone or Pech coal; it is deep black, lustrous and has conchoidal fracture, but gives a very dark color to solution of caustic potash. It is of merely local importance, as the greatest thickness is little more than a half meter, yet at one time the annual output was 60,000 Centner. Near Klittsdorf, a sandy brown coal contains remains of wood; near Löwenberg, coal, 6 inches thick, is exposed and lower down in the section is a mass of coal and sand, containing 6 inches of good coal, but in greatest part is mixture of coal and sand in about equal proportion; at another exposure the composition is clay and fragmentary coal. Scupin thinks that this confused mass must be allochthonous and suggests that it may represent a washed out swamp. Two lower beds, 10 and 3 inches thick, were pierced in a boring and a notable quantity of sphærosiderite was found in the intervening rocks.

The Cenomanian coal of Bohemia is usually unimportant. Naumann says that the Lower Quadersandstein occasionally contains layers of clay shale rich in conifer and dicotyledonous remains, with nests and layers of mostly unworkable coal. v. Andrian gives the section obtained near Chrudim, about 60 miles east-southeast from Prag: (1) Coarse sandstone, with fossils, 24 feet; (2) dark clay

<sup>8</sup> Hosius, *Zeitsch. d. d. Geol. Gesell.*, Vol. 12, 1860, p. 61.

<sup>9</sup> H. Scupin, "Die Entstehung der Niederschlesischer Senon-Kohlen," *Zeitsch. f. pr. Geologie*, 1910, pp. 254-257.

shale, with plant remains and coaled stems, 4 to 5 feet; (3) moderately coarse sandstone, 2 to 3 feet; (4) coarse conglomerate, 2 to 4 feet. The dark shale of this region section contains near Skutsch, 12 miles farther west, a bed of worthless Pechkohle, which is rich in Bernstein. Reuss, in a letter to Beyrich, stated that a mass of Bernstein, several inches long and of brownish yellow color had been obtained as Skutsch, which is very near the Moravian border.<sup>10</sup>

In Moravia, according to Reuss,<sup>11</sup> the coaly substance, to which the Lower Quader beds owe their color, is sometimes collected into nests or even into beds of workable thickness. At a mine, west from Mährens-Trubau and about 50 miles southwest from Chrudim, he saw a seam of thinly laminated Moorkohle [a peat-like brown coal] 4 feet thick, brownish-black and containing laminæ of bright black Pechkohle. It slacks readily on exposure and is high in ash. Grains of honey-yellow Bernstein, some as large as a pea, are scattered through it. The roof and floor are blackish-gray shale. In older mines near Utigsdorf, farther south, Reuss saw two coal seams, 1 foot 6 inches and 3 to 4 feet thick. Coal of the upper bed is brown-black, with shaly structure, rather bright fracture and contains much resin. The coal of the lower bed is black, rather crumbling, contains numerous layers of Faserkohle as well as many lumps and half-inch layers of Pechkohle. Bernstein is less abundant than in the upper bed. Roof and floor of both beds are dark, more or less sandy.

Coal has been mined for many years in Lower Austria, near Grünbach, at a score of miles south from Vienna and near the border of Hungary. The deposits are in the Gosau formation, which is taken to be of Turonian or Senonian age. Čžžek<sup>12</sup> states that the seams are all thin south from Grünbach, but become thicker north from that city. The Alois tunnel, 1,200 feet long, intersects 21 seams of which only 3 are workable, the others being from 2 to 10 inches thick. The workable beds, all within vertical distance of

<sup>10</sup> Reuss, *Zeitsch. d. d. Geol. Gesell.*, Band III., 1851, p. 13; F. v. Andrian, *Jahrb. k. k. Geol. Reichsanst.*, Vol. XIII., 1863, p. 207.

<sup>11</sup> A. E. Reuss, "Beiträge zur geognostischen Kenntniss Mährens," *Jahrb. k. k. Geol. Reichsanst.*, Vol. V., 1851, pp. 727-731.

<sup>12</sup> J. Čžžek, "Die Kohle in den Kreideablagerungen bei Grünbach," *Jahrb. k. k. Geol. Reichsanst.*, Vol. II., Pt. 1, p. 144, Pt. 2, pp. 107 et seq.

60 feet, are the *Caroli*, 2 to 3 feet, very irregular in thickness, but its coal is much prized, as it is low in ash and clean, the bed being without a parting. *Jodahofer*, 3 to 4 feet, is usually quite regular, but at times the intervening rocks disappear and this unites with the *Caroli*, the thickness increasing greatly and occasionally reaching 10 feet. *Antoni*, 2 to 2 feet 6 inches, is in 3 benches with clay partings, each 2 inches. The coal is soft in top and bottom, but in the middle bench it is hard. The roof is black slate, 1 foot, which burns well. As described by Čížek, it is a cannel-shale, a mud very rich in organic matter.

The coal is pitch-black, with bright luster and black-brown streak. No woody structure is visible to the unaided eye. Occasionally one finds pieces which retain the form of branches, but all trace of fiber has disappeared. Analyzed by Schrotter, the composition is: Carbon, 74.84; hydrogen, 4.60; oxygen [and nitrogen], 20.56; water at 100° C., 6.57; ash, 6.92. Reasoning from this analysis, Čížek concludes that the character of a coal has some relation to its age. The Tertiary coal at Brenenberg has only 60 to 70 per cent. of carbon, while that from the Lias at Fünfkirchen has 85 to 86 of carbon and only 8 to 9 per cent. of oxygen.

Passing over into Hungary, one finds, according to Hantken,<sup>13</sup> important development of Cretaceous coals in the province of Bakony and in the western mountains. The areas are insignificant in comparison with those of the Lias, but the beds are little disturbed, mining is simple and the output is large. The important mines are near Ajka in Bakony, where the Cretaceous consists of two marine formations separated by a fresh-water formation with coal seams. The fauna contains some brackish-water forms but fresh-water types predominate. There are at least 25 seams of coal, of which one near the top and another near the bottom are workable. The upper or Bernstein Flötz is always divided into several benches and the coal is inferior. In one part of a mine this bed is 2.93 meters thick with 4 benches of coal aggregating 1.70 of coal, while in another part it is 2.43 meters thick and in 6 benches, but the thickness of coal is practically the same, 1.72 meters. The lower

<sup>13</sup> M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in der Ländern der ungarischen Krone," Budapest, 1878, pp. 174, 176-179, 197, 198.

bed averages about 2 meters. Sometimes it is without partings but at others it is broken by two, 20 to 50 centimeters thick. Occasionally, one of the other beds is thick enough for mining, but in all cases the thickness shows much variation. The coal is of very fair quality; in the Barod area, moisture is from 8.2 to 10.4 per cent. and the ash is from 7.1 to 15.7 per cent.

In the Lower as well as in the Upper Cretaceous, coal seams accumulated on border areas, where the sediments show proximity to land. The character of the deposits, the lens-shaped coal seams and the fresh-water fauna associated with them seem to justify the suggestion that the coal was formed in swamps on great irregular river plains. For the most part, these had a comparatively brief existence and were subject to frequent floods carrying muddy water.

#### AUSTRALASIA.

Molengraaff<sup>14</sup> reports that he saw thin seams of coal at various horizons in the Cretaceous along several rivers in central Borneo. These are without economic importance. The associated sandstones frequently contain grains of coal.

Coal is present in the Cretaceous of eastern Australia, though very rarely in economic quantity. As the conditions appear to be much the same throughout, it suffices to consider the phenomena in Queensland as described by Jack.<sup>15</sup> Cretaceous deposits cover a great part of that province, where they are divided into the Upper or Desert Sandstone and the Lower or Rolling Downs formation.

The Desert Sandstone formation, now remaining in barely one twentieth of its original area, consists mostly of thin flags, whose surfaces are covered with a network of raised lines, crossing each other at all angles, which clearly represent filled sun cracks. The same sands show tracks and burrows as well as indeterminate remains of plants. Cross-bedding is quite characteristic of the thicker layers. Pebbly deposits occur occasionally and, at one locality, Gibb saw an angular quartzose grit which passed into brecciated

<sup>14</sup> G. A. F. Molengraaff, "Geological Explorations in Central Borneo," Eng. ed., Leyden, 1902, pp. 202, 217, 241, 250, 277, 318.

<sup>15</sup> R. L. Jack and R. E. Etheridge, Jr., "Geology and Palæontology of Queensland," Brisbane, 1892, pp. 397-403, 511-536, 551, 558.

conglomerate. Silicified stems of trees and of bamboo-like plants were observed in many beds. On top of a small table-land in western Queensland, H. Y. L. Brown discovered a grove of fossil stumps standing erect. Thirteen are large, the greatest diameter being 4 feet and the usual height is 4 feet 6 inches. Many of the stumps are hollow and fragments lie in all directions. "The matrix having been denuded, they stand as evidence of how trees have degenerated in size in this part of the country since Cretaceous times."

The features of this formation throughout are those of a vast flood plain, subject to frequent overflow and to frequent changes in direction of drainage. As one should expect, the coal deposits of the Desert Sandstone are lenses of moderate extent and commercially unimportant. Within the Cooktown region, seams were seen 6 and 15 inches thick; the bottom of the latter is crowded with quartz granules. The coal is worthless; four samples from the Cooktown region gave 9.65, 19.02, 30.20 and 36.53 per cent. of ash. The coals vary from semi-bituminous to high-grade bituminous, though in the description of this region, no reason for this difference appears. Pellets of coal were seen frequently in rocks associated with the coal.

The Rolling Downs formation is mostly marine, with intercalated deposits, which may be of fresh-water origin. The higher rocks on the Upper Flinders River contain bands of ferruginous sandstone with markings which are suggestive of reptilian footprints. Farther up the river are thick-bedded sandstones, with grits, pebbly grits and conglomerates. These hold coal seams, one of which is in five benches with 22 inches of coal and a total thickness of 4 feet 9 inches. Other but thinner seams were seen in this neighborhood. The coal is very good and cakes. Near Winton, borings have passed through some seams of coal, but all are thin, none exceeding 2 feet, and the coal in the several seams varies, the ash being from 4.58 to 20.34 per cent. Some seams, 3 feet thick, have been observed elsewhere in Queensland, but they are merely lenses, marking sites of swamps occupying depressions in sandy river plains.

Identifiable remains of plants are rare in the Queensland Cre-

taceous, only two forms having been recognized. One of them belongs to *Glossopteris* and was found in the Desert Sandstone. Etheridge cannot distinguish it from *G. browniana* and *G. ampla*, which abound in the Permo-carboniferous of Queensland and New South Wales. The important coal deposits of New Zealand, in the lower part of the Cretaceo-Tertiary, occupy some extensive areas in the South Island and a less important area in the North Island. The South Island was studied in detail long ago by Hector<sup>16</sup> and his associates. Hector examined Nelson district, the northern part of the island. The coal-bearing rocks at the Collingwood mine, in the extreme north, rest on 105 feet of conglomerate and are 250 feet thick. They are mostly thick-bedded clayey sandstones with interbedded carbonaceous shales, which have 6 coal seams, from 1 to 4 feet thick. But the coal is broken badly by partings. On the Ngakawau River there is a seam, 16 feet thick and yielding good caking coal, which burns freely with a sooty flame. In the lower canyon of Buller River, he saw a bed of compact brown coal, at least 16 feet thick, underlying brown micaceous sandstone and overlying a conglomerate or breccia of great thickness, which has a few thin seams of coal. The thick seam, which has much fossil resin, varies in composition; samples from different parts of the bed have from 33.45 to 46.85 per cent. of volatile combustible matter in the pure coal. The ash in raw coal is about 7 per cent. A seam, 20 feet thick, is mined on a branch of Buller River; its ash is remarkably low, varying from 0.98 to 1.19 per cent. The coal in some parts of the seam is compact, with bright luster and splintery fracture, but in others it is dull, with fracture like that of brown coal, and resembles jet.

In the Grey River area, the southwest corner of the district, the basal rocks are conglomerate and breccia, succeeded by 200 to 800 feet of sandstones, grits and shales with beds of anhydrous caking coal. Above these is a non-persistent conglomerate. Where this last is absent, the sandstones pass gradually into sandy clays with marine fossils and nodular clay iron-stone. Immediately below these marine beds and resting on the conglomerate or, in its absence,

<sup>16</sup> J. Hector, "Geological Survey of New Zealand," 1872, pp. 129-141, 158-165.

on the sandstones, is a seam of inferior coal, the "upper bed," which is a pitch coal, containing much resin and little constitutional water. The thick bed on Grey River, 16 feet, contains 64 to 68 per cent. of fixed carbon, while another seam, on the coast, has but 38.55 per cent. Hector described the latter as a very superior pitch coal, but its chemical composition suggests cannel; and it was recognized as such by Campbell,<sup>17</sup> who notes its variations in thickness. Within its small area, he saw it 4, 6, 16, 4, and 2 feet. At the border, it thins away to nothing. Cannel is the prevailing type in this bed. Another bed, resembling splint, contains pebbles of sandstone.

A more detailed study of the Buller Coal Field was made by Cox and Denniston.<sup>18</sup> At Coalbrookdale in Waimangawa Basin, Cox saw two coal seams, 5 and 18 feet thick, separated by 34 feet of sandstone; but at a short distance away they become 6 inches and 11 feet 6 inches. The upper bed quickly disappears but the lower one thickens northwardly until it becomes 40 feet, beyond which it decreases. Still farther north, beginning at Mount Frederick in the Ngakawau Basin, this lower seam is 5, 25, 37, 40 and, at center of the basin, 53 feet; thence it thins away in all directions, the last measurement being 6 inches. Other beds show similar variations. Southwardly from the Waimangawa Basin, the conditions are the same. Descending a stream from Mount Williams, Cox saw an outcrop of shale; at a little distance beyond, this became a coal seam, 3 feet thick, but worthless because of numerous shale bands. Followed southwestwardly, this, the lower coal seam of other basins, became 3, 8, 20, 40, 20, 20, and 25 feet. But southward from the last measurement the seam thinned away until no trace of it could be found.

Denniston's descriptions and his numerous sections show the lens form of the coal seams, thickest at center and thinning away to disappearance toward the margins of the basins. He notes that coal of the lower seam is not the same throughout a basin. In one area the upper portion is tender but the lower is hard; in another, the prevailing type is splint or cannel, hard, compact, jetlike, burning

<sup>17</sup> W. D. Campbell, New Zealand Geol. Survey, Reps. for 1876-7, pp. 31-40.

<sup>18</sup> S. H. Cox, N. Z. Geol. Survey, Reps. for 1874-6, pp. 17-29, 106-119; R. Denniston, the same, pp. 121-171.

with a candlelike flame and showing little tendency to cake. The descriptions by Cox and Denniston make clear that the basins were contemporaneous but not connected.

The district of Canterbury, embracing the middle eastern part of the island, was examined by Haast.<sup>19</sup> The Malvern Hills area, about 30 miles west from Christchurch and embracing not far from 180 square miles, exhibits his Great Brown Coal Formation, which, in the Table of Formations of 1879, is placed at base of the Cretaceous-Tertiary. The coal seams are numerous, usually thin and always variable. Occasionally, nodules of retinite are numerous. The intervening rocks show great irregularity in structure. Sandstones have abundance of tree trunks, whose thick bark has been replaced with clay ironstone, while the interior tissue has been replaced with "woodstone" or filled with black shaly material.

The extensive district of Otago, embracing the southern part of the island, was examined by Haast, McKay and Hutton.<sup>20</sup> In Haast's area the lower part of the column has near the base a mass composed of subangular fragments of schists and containing irregular seams of coal, 6 to 15 inches thick. Higher up, the rock becomes a conglomerate with well-rounded pebbles of quartz. The thin-bedded sandstones and shales following this conglomerate have only thin seams, but in the upper part of the column there are beds of conglomerate separated by thinner shales and sandstones, which hold important coal seams.

Coals are mined on Green Island. Near one of the shafts, McKay saw a bed of fossilized roots "sticking in an old soil, just as they grew." At another locality, a workable coal seam underlies beds containing *Belemnites*.

According to Hutton, the area of Cretaceous coals is small in Otago. The most important field is near Shag River, where there are at least 6 workable seams, yielding the best of brown coal. The seams are thin in the Mount Hamilton field, rarely exceeding 10 inches, but the coal is bituminous. The highest sandstone there contains at base an angular block of sandstone, 8 by 3 feet, resting on

<sup>19</sup> J. Haast, N. Z. Geol. Repts. for 1871-2, pp. 1-88.

<sup>20</sup> J. Haast, Repts. for 1871-2, pp. 148-153; A. McKay, Repts. for 1873-4, pp. 59, 60; F. Hutton, "Geology of Otago," Dunedin, 1875, pp. 44, 100-103.

a thin seam of coal. He conceived that it had been floated in, attached to the roots of a tree, "wherefore the coal beds are formed partly from driftwood."

The coals of New Zealand for the most part are lignitic or sub-bituminous, but no woody structure is mentioned by any observer.

#### GREENLAND.

The existence of coal in the Cretaceous of western Greenland was made certain by the work of White and Schuchert<sup>21</sup> during 1897. Their observations were made chiefly on the Nugsuak Peninsula. The Komé or lower division, as exposed near Kook, consists of shaly or laminated sandstones with thin beds of dark shale containing much carbonaceous matter, so abundant at times as to make the shale combustible, but not enough to justify one in calling it coal or lignite. The whole succession is so irregular that sections are not comparable. The plants are conifers, cycads and ferns with some indeterminate leaves of dicotyledons. Near Ugarartorsuak, all divisions of the Cretaceous were examined. The Komé, in a section of 270 feet, has 20 feet of "thin coals with shaly partings and 2 bands of carbonaceous shale." Another section of about 305 feet, belonging to the Atane or middle division, has several beds of coaly shale, a coal seam, 1 foot 6 inches and a mass of "thin sandstones and coals," 10 feet. The flora differs from that of the Komé as, besides cycads, conifers and ferns, it has 8 species of dicotyledons. A third flora, in still higher beds, is related to the second and both seem to be related to the Upper Cretaceous. Dark beds with huge ferruginous concretions, have fossils of types characterizing the Montana of western United States.

A dark shale, 75 feet thick, seen near Ata on the southerly shore of the peninsula, has leaves and large fragments of tree trunks with an invertebrate fauna, which Stanton takes to be the same with that of the highest beds on the north shore and equivalent to Cenomanian. The highest division of the Cretaceous, Patoot of Heer, is exposed near Patoot, where the lowest beds are at 470 feet above the sea. The fossils are of Senonian age and some of the plants are

<sup>21</sup> D. White and C. Schuchert, "Cretaceous Series of the West Coast of Greenland," *Bull. Geol. Soc. Amer.*, Vol. 9, 1898, pp. 343-368.

allied to Laramie forms. The authors suggest that, at least in part, the Patoot may be a transition formation; no unconformity was observed between Cretaceous and Tertiary; all conditions indicate that sedimentation was continuous. Near Patoot, at 1,170 feet above the base of this division, there are occasional bands, ferruginous, containing ferns, conifers, and dicotyledons, with erect stumps and abundance of silicified wood.

#### NORTH AMERICA.

Cretaceous deposits are present on the Atlantic and the northern Gulf coasts of the United States, but they contain no coal and the occurrences of lignite have interest only for the paleobotanist. The important area is in the west-central region, where the deposits originally extended from the 95th meridian westward for not far from 1,000 miles, and from Lat. 25° in Mexico northward for not less than 2,100 miles, in all not less than 2,000,000 square miles. These figures are merely approximations and the area of greatest extent may have been considerably larger. The continuity of these deposits was destroyed by post-Cretaceous erosion, following the Rocky-Mountain revolution.

Belief that Cretaceous deposits were practically continuous throughout this vast area is of comparatively recent data. The prevalent conception until within little more than 20 years, was that the Rocky Mountains had existed during Cretaceous time. There seems to be little room for doubting the general accuracy of conclusions that those mountains mark lines of successive foldings but proof of their existence as elevated areas is wanting. Willis<sup>22</sup> thought that the earliest Cretaceous deposits of his district were laid down on a surface of Carboniferous and Algonkian rocks, which was a plane, primarily a peneplain and afterwards a surface of marine planation. The first period of compression may not have begun until after close of the Cretaceous. Incidental reference to the conditions indicates similar conception on the part of some later observers; but the first clear analysis of the evidence, known to the writer, is that by Lee,<sup>23</sup> who has discussed the phenomena observed by him-

<sup>22</sup> B. Willis, "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 338, 339.

<sup>23</sup> W. T. Lee, U. S. Geol. Survey, Prof. Paper, 95-C, 1915, pp. 56-58.

self and others in New Mexico and Colorado. He recognizes peneplanation in the southern Rocky-Mountain region prior to the beginning of the Upper Cretaceous. The evidence all indicates that the interior continental sea extended from Utah and Arizona eastward over the present site of the Rocky Mountains.

The source of sediments was at the south and west, as appears from discussions by Lee, Stone and Calvert and Stebinger,<sup>24</sup> as well as from sections by many other observers. The coarser materials are in the southern and western parts of the area, while, toward the east, land and border-land conditions disappear, so that the rocks become shales with more or less of limestone. But toward the close of the Cretaceous, land and shore deposits extended far east, indicating perhaps a long period of comparative stability prior to the great mountain-making period of the Tertiary. The vast area, reaching in some places almost to the Mississippi, was apparently at first almost a peneplain, over which the early Cretaceous sea advanced to the western border.

During and after the Rocky-Mountain revolution, erosion was so energetic that, in New Mexico, Arizona, Utah and Colorado, the Cretaceous was broken into isolated "fields" or "basins," separated in many cases by ranges showing Archean rocks at thousands of feet above the general altitude of the region. But this greatly disturbed area becomes narrower toward the north, so that, in much of Wyoming, the continuity is broken only by comparatively short ridges around which the Cretaceous rocks outcrop. Still farther north, the undulations in by far the greater part of the area are gentle and sedimentation appears to have been continuous into the Tertiary; the greatly disturbed region on the western side trends toward the northwest and becomes very narrow. During the Cretaceous, deposition was practically continuous, there being only local unconformities, so small vertically and horizontally as to be surprising, in view of the vast area under consideration. There are, however, great variations in thickness which seem to be due to differential subsidence. The conditions favoring accumulation of coal were repeated many times in the region of coarser sediments and

<sup>24</sup> W. T. Lee, Prof. Paper, 95-C; R. W. Stone and W. R. Calvert, *Econ. Geol.*, Vol. V., 1910; E. Stebinger, Prof. Paper, 90-G, 1914.

the formation of offshore deposits was marked by an assemblage of fossils which survived the changing conditions and reappeared at several horizons.

It was to be expected that during the period of reconnaissance surveys, coal groups belonging near the base of the Upper Cretaceous should be correlated with others elsewhere, which are in highest formations of the series. One familiar with the facts, as now understood, is not astonished by the contradictions, when he considers the conditions under which the earlier work was done. During recent years, detailed studies by geologists of the National surveys of the United States and Canada have done so much toward removal of uncertainties, that it is possible to present a comparative table of formations, which, as a generalization, is near enough to the truth for purposes of this study.<sup>25</sup>

The first systematic classification of the western Cretaceous was presented by Hall and Meek.<sup>26</sup> Hall had financed an expedition to make collections between the Missouri River and the Mauvais Terres, Meek being in charge. The succession, based chiefly on Meek's observations, is

Eocene, Tertiary Formation, clays and sandstone, etc., containing remains of mammalia, 250 feet.

Cretaceous Formation,

5. Arenaceous clay, passing into argillaceous sandstone, 80 feet.
4. Plastic clay, with calcareous concretions containing numerous fossils. This is the principal fossiliferous bed of the Cretaceous on the upper Missouri, 250 to 300 feet.
3. Calcareous marl, containing *Ostrea congesta*, scales of fish, etc., 100 to 150 feet.

<sup>25</sup> The writer would not neglect acknowledgment of his great indebtedness to the writings of W. T. Lee, T. W. Stanton, N. H. Darton, F. H. Knowlton, E. Stebinger, R. W. Stone and W. R. Calvert, of the United States Geological Survey and to those by D. B. Dowling, of the Geological Survey of Canada. Several of these students have been unreserved in communicating unpublished material; but they must not be held responsible for conclusions offered by the writer, some of which may appear to them far from correct.

<sup>26</sup> James Hall and F. B. Meek, "Descriptions of New Species of Fossils, from the Cretaceous Formation of Nebraska," *Mem. Amer. Acad. Arts and Sci.*, 1856, p. 405.

2. Clay containing few fossils, 80 feet.

1. Sandstone and clay, 90 feet.

The thicknesses were purely tentative, as the party, owing to unexpected complications, were compelled to make a remarkably rapid reconnaissance. Several years later, Meek and Hayden published an amplified section, based on examinations and collections made by Hayden while associated with the Reynolds expedition.<sup>27</sup> In this memoir, geographical names were applied to the several formations, Fox Hills beds, No. 5; Fort Pierre group, No. 4; Niobrara division, No. 3; Fort Benton group, No. 2; Dakota group, No. 1.

The Fort Union or Great Lignite Group, which overlies the Fox Hills, was placed in the Tertiary. This grouping was based on the fossil remains, not on the lithological features and it was applicable apparently throughout the eastern part of the Cretaceous region. In the early 70's discussion arose respecting the relations of some coal deposits which had been referred to the Fort Union; the term "Laramie" was introduced for the deposits in dispute, to be employed without committing the writer to either Tertiary or Cretaceous age. Studies in more recent years made necessary a change at the base of the column. Darton's examination of the Black Hills in northeastern Wyoming showed that the Dakota is complex, that the middle and lower portions carry Lower Cretaceous forms, while the upper portion belongs to the Upper Cretaceous. Some years afterward, the same author, and later Lee and Stanton, discovered fossils with similar relation in the same beds within New Mexico. These lower beds were correlated with the Kootenai of Canada.

When, however, an attempt was made to apply the Missouri River section to the country west from the 106th meridian, serious difficulty was encountered. The character of the deposits was wholly different. The matter was complicated by the fact that the earlier explorers did not recognize that the great erosion was due to post-Cretaceous elevation of the mountains and by the other fact that they did not know that a grouping of fossils, resembling that of the Fox Hills, occurs in that region low down in the column. In

<sup>27</sup> F. B. Meek and F. V. Hayden, *Proc. Acad. Nat. Sci.*, Philadelphia, 1861, citations from pp. 419, 432.

the later work, exigencies made necessary the study of economically important districts and the temporary ignoring of intervening districts. The column was divided for descriptive purposes, largely on the basis of lithology and local names were introduced, which were utilized in other districts, but not always in the same sense. At an early date, the difficulty in determining boundaries of formations at the west was recognized; the Fox Hills and the Pierre were combined as the Montana and the Niobrara and Fort Benton as the Colorado. In this study, the Meek and Hayden classification is employed as it is based on palæontological ground and enables one to recognize changes in physical geography. As modified by later studies it is

Laramie	
Montana	{ Fox Hills
	{ Pierre
Colorado	{ Niobrara
	{ Benton
Dakota	
Kootenai.	

Each of the several formations is coal-bearing in areas of greater or less extent, but barren or nearly so in others of greater extent. They will be described in the order of age. Literature dealing with the coals of the western Cretaceous is voluminous, but it consists largely of preliminary studies with land classification as the object. Much of the region is very sparsely settled, as it is agriculturally arid, and systematic mining is confined to narrow strips along the railways. For the most part, explorers must depend on natural exposures, which are indefinite. At the same time, one cannot refrain from grateful acknowledgment of the skill exhibited by not a few of the observers, for the mass of information is so great as to prove an embarrassment in preparation of this review.

*The Laramie, Lance, Edmonton.*

The post-Cretaceous erosion spared only scattered areas of Laramie in the southern districts, but farther north, where the region of orogenic disturbance was restricted more and more to the far

western border and deposition was apparently continuous in the plains, Laramie covers or underlies great spaces.

In the present state of knowledge, one may not assert or deny the existence of Laramie beds in the important Trinidad-Raton field of Colorado and New Mexico. Lee's discovery of an unconformity by erosion in the mass, formerly regarded as Laramie, has made the relations of the Raton formation, that above the unconformity, somewhat uncertain. The plant remains appear to have Tertiary affinities. The report by Lee and Knowlton on this field is still unpublished. It would appear that the Laramie is present in the isolated coal field on the Arkansas River, near Canyon City, Colorado. Stevenson<sup>28</sup> in his first report referred all the coals of this field to the Laramie; but at a later date, he restricted that formation to the upper part, 880 feet, which is in accord with the later measurement by Washburne. This later observer obtained plant remains which show that the rocks are equivalent to a part, at least, of the Laramie as recognized farther north in the Denver Basin. The coal seams are irregular in occurrence and appear to be mere lenses. The sandstones and shales are so variable that vertical sections, less than 100 yards apart, are wholly dissimilar.

The Denver Basin extends along the eastern foot of the Front Ranges almost to the northern boundary of Colorado. The Mesozoic deposits were studied by Eldridge.<sup>29</sup> The Laramie, 600 to 1,200 feet thick, consists mostly of sandstones in the lower, but of clays in the upper part. Coal seams in the higher beds are thinner and much more irregular than those in the lower division, which is about 200 feet thick. *Ostrea glabra*, according to Eldridge, occurs in the lower division, so that in the writer's opinion this sandstone is closely allied to the Fox Hills, to which it is lithologically similar. Sections throughout show great variation in the rocks as well as in the coal seams, so that in any district, strict correlation of coals in different mines is possible only where the workings are continuous. The coal seams of the lower division are from 3 to 14 feet thick. A seam,

<sup>28</sup> J. J. Stevenson, U. S. Expl. W. of 100th Mer., Vol. III., 1875, pp. 393-397; *Proc. Amer. Phil. Soc.*, Vol. XIX., 1881, pp. 505-521; C. W. Washburne, U. S. Geol. Survey, Bull. 381, 1910, pp. 341-378.

<sup>29</sup> S. F. Emmons, W. Cross, G. H. Eldridge, U. S. Geol. Survey, Monog. 27, 1896, pp. 51-74, 323-369.

mined in the Lafayette district, is 14 feet thick at the outcrop; but within 500 feet a parting appears, which increases northwardly to 10 and at length to 25 feet. The splits remain good in this direction, but southwardly, as the parting increases, the lower split is broken more and more by slates until it becomes worthless. The coal in some seams is not the same throughout; one bench may be hard, another soft. In one bed, the upper bench yields softer coal than the lower, which is complex, consisting of: Bright coal with conchoidal fracture, 6 inches; crushed coal, 6 inches; fibrous coal, 36 inches. The coal of the Denver Basin often has woody structure and contains silicified tree trunks, knots and branches. It is resinous at many places.

D. White<sup>30</sup> states that, while the coals of this Basin are relatively persistent, they vary greatly in thickness. The topography of the floor reveals shallow "swales" or ponds, occasionally extending a mile or more, in which the coal is thicker. The floor at Lafayette is a bluish sandy underclay, containing numerous roots in place, probably an old swamp soil; resting on this is a bed, 8 to 30 inches thick, of dark carbonaceous clay, or lignitic mud, filled with flattened stems, lying in all directions, some of them very large and many are much compressed. The roof is sandstone with no transition from the coal.

In general, the coal is essentially xyloid, there being apparently more wood than in the lignite of Hoyt and Rockdale in Texas, though less than in that of Wilton and Lehigh in South Dakota—all of them Eocene. The quantity of jetified wood is large but the branches and limbs are compressed to thin lenses. Mineral charcoal is abundant, often in large fragments. A log was seen, 14 by 5 inches in section, jetified in the interior, while the outer portion had become mineral charcoal; but another specimen was hollow, containing mineral charcoal in the interior, while the outer portion was jetified. Irregular lumps of yellow resin are numerous and at times this material has been squeezed into the joints.

The coal at Marshall, 10 miles from Lafayette, is at the same horizon, being regarded as one of the splits of the main Lafayette seam. Silicified wood is abundant and well-preserved, showing

<sup>30</sup> D. White, "The Origin of Coal," Bur. of Mines, Bull. 38, 1913, pp. 20-23.

grain and rings distinctly. The lower part of the bed is more conchoidal, less xyloid and has higher percentage of fixed carbon than the upper, suggesting, as White says, that it represents a more matured peat. He could obtain no data respecting the floor of this bed, but roots were found under two coal seams in a railway cut, the sandy floor of one being undoubtedly an old soil.

Thiessen's<sup>31</sup> microscopic study of the Lafayette and Marshall coals proved that, generally speaking, the type of vegetation and the conditions during accumulation must have been very similar to those during the Eocene in Montana and Dakota, though the proportion of woody materials is somewhat less and the compression is greater. The resin is darker than that of the Dakota lignite. The débris contains the reticulated bodies observed in the pith of certain fossil wood and present in all Tertiary and Cretaceous coals which Thiessen has examined. Fungal hyphæ and spores are abundant, the former especially in material of herbaceous origin. Spores and pollen exines compose not more than 5 to 10 per cent. of the mass.

A notable area of Laramie has escaped erosion in the northern part of the San Juan Basin within New Mexico and Colorado. On the eastern outcrop, according to Gardner,<sup>32</sup> coal seams are very thin or are wanting; but on the western outcrop, Shaler saw along the Rio Chaco several coal seams which occasionally become workable, with a maximum thickness of 3 to 6 feet. Farther north, on the San Juan and Plata Rivers, he saw the Carbonero seam with maximum thickness of 50 feet; but it is variable, for at one locality it is little more than 6 feet and is broken by three partings. Beyond the Colorado line, near Carbon Junction, the thickness increases to about 100 feet; the partings are very numerous, but there are some bands of clean coal, 4 to 5 feet thick. The bed divides toward the west; at 3 miles southeast from Durango, Shaler saw three seams, 7, 30 and 15 feet, in a vertical space of less than 200 feet, which he believes to be splits of the Carbonero.

Apparently no part of the Laramie has escaped erosion in the great Uinta Basin of northwestern Colorado; or, at least, if any still remain, its rocks are so similar to those of the Pierre that no

<sup>31</sup> R. Thiessen, Bur. of Mines, Bull. 38, 1913, pp. 241-243.

<sup>32</sup> J. H. Gardner, Bull. 341, 1909, p. 388; M. K. Shaler, Bull. 316, Pt. 2, 1907, pp. 385, 386, 395, 396, 400, 404.

separation can be made. The coal deposits of this region were referred to the Laramie by the earlier observers; the later observers have proved that they in the Pierre.

Laramie coals are important in the Green River Basin of southwestern Wyoming. The Cretaceous section in the outlying coal field of Coalville in northeastern Utah has on top 2,500 feet of mostly sandy beds, with leaves and fresh-water shells, but no coal. This rests on 1,650 feet of sandy beds with marine fossils.<sup>33</sup> At about 30 miles northeast, one reaches the Laramie area of Uinta County, Wyoming, where the Laramie, according to Knight and Veatch,<sup>34</sup> is more than 5,000 feet thick in the southern part of the county. There, as in the Coalville field, one is near the western border of deposition and the formations are thick. Schultz found only 2,800 feet remaining in the northern part of the county. The lower portion of the column for several hundred feet contains marine fossils and it must be referred to the Fox Hills; but Laramie leaves are abundant in the higher deposits. The Tertiary coals of Evanston overlie the Laramie unconformably. Coal seams are numerous in the Laramie and at times they are workable, but the thicker seams of the Tertiary render them unimportant.

The Rock Springs coal field in Sweetwater County is about 50 miles farther east, only Tertiary deposits being at the surface in the intervening space. Schultz<sup>35</sup> gives the thickness of Laramie as 3,900 to 1,500 feet, the variation being due to extent of erosion. The lower part of the section is clearly Fox Hills; the Laramie beds are sands and clays with little coal. The marine sandy beds persist eastwardly and the Laramie rocks retain their features, finer in grain, more argillaceous and without important coal beds. In southern Carbon County, Ball and Stebinger<sup>36</sup> find an extreme thickness of 4,000 feet, but the formation thins away southward. The lower part of the column for about 400 feet must be assigned to the

<sup>33</sup> C. H. Wegemann, *Bull.* 581-E, 1915, p. 161.

<sup>34</sup> W. C. Knight, "Southern Uinta County, Wyoming," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 542-544; A. C. Veatch, *Bull.* 285, 1906, p. 333; A. R. Schultz, *Bull.* 316, 1907, p. 217.

<sup>35</sup> A. R. Schultz, *Bull.* 341, 1909, p. 259; *Bull.* 381, 1910, pp. 223, 227.

<sup>36</sup> M. W. Ball and E. Stebinger, *Bull.* 341, 246, 253; *Bull.* 381, pp. 190, 193, 204.

Fox Hills. The coal seams are irregular except in the northern part of the district, where beds were seen, 8, 6 and 4 feet thick. Whether these belong to Fox Hills or to Laramie cannot be determined from the sections. In the southern portion of the basin, within Colorado, the Laramie is 900 feet thick according to Fenneman<sup>37</sup> and Gale, consisting of alternating sandstones and shales, with indications of 20 lignite seams distributed irregularly in the upper two thirds. The writer regards the lower third as belonging to Fox Hills and thinks that the thick coal seam near Craig, 8 feet, is in that formation.

Northward from the Green River Basin, areas of Laramie are comparatively unimportant. On the west side of the Bighorn basin, lenticular coal beds were seen by Woodruff at many places in the lower part of the formation. Washburne found 150 to 700 feet between the Eocene and the Pierre formation, massive sandstones and shales; in this, taken to be Laramie, there are thin and variable coal beds. The only workable seam is near Garland where 4 feet of clean coal had been worked; but the seam quickly breaks up in all directions and becomes worthless. The Buffalo coal field, east from Bighorn Mountains, shows great irregularity in deposition during the Laramie, but the coal seams, though varying in thickness and quality, can be traced for considerable distances. In the Sussex coal field, 30 miles farther south, Wegemann found the Lance formation, 3,200 feet thick and resting on the Fox Hills. The coals are unimportant except in two localities, where seams occasionally become workable. Wegemann's descriptions seem to make clear that the coals are mere lenses and the better coal is in the middle portion of the lens. Winchester measured about 2,450 feet of Lance beds in the Lost Spring coal field, which is on the western border of the great Tertiary lignite area. There are traces of the coals seen farther west, but only carbonaceous shale was found. The Fox Hills, Lance and Fort Union appear to be conformable in this region. The highest rocks in the Black Hills area of north-eastern Wyoming are sandstones, shales and lignites, in all about 2,500 feet, as determined by Darton. That student hesitated to identify these beds as Laramie, because it was not possible to determine whether or not they are conformable to the underlying Fox

<sup>37</sup> N. M. Fenneman and H. S. Gale, Bull. 285, 1906, p. 288.

Hills. The relations of the Lance formation have been subject for much discussion; the testimony of plant and animal remains is contradictory. In no inconsiderable area, the Lance is conformable to the Fox Hills. Winchester in a recent note, summarizing results obtained by himself and his assistants, in eastern Wyoming, states that Lance overlies Fox Hills. It is subdivided into three members; a lower undifferentiated portion, 425 feet thick; a middle, lignite-bearing portion, the Ludlow, at least 350 feet; and an upper marine member, the Cannonball, 225 feet. The marine fauna of the Cannonball is very similar to but not identical with that of the Fox Hills, while flora of the Ludlow cannot be differentiated from that of the Tertiary Fort Union.<sup>38</sup>

The eastern half of Montana is a rolling plain covered with Tertiary and later deposits, the mountains of states at the south having disappeared. Anticlinals have brought up the highest members of the Cretaceous. The Lance, taken by the writer as the eastern extension of the Laramie, has at base the Colgate sandstone, which is 90 to 175 feet thick and contains no coal except at one locality, where Hance saw a lens only a few hundred yards long. The upper part of the Lance, about 500 feet, has variable seams of lignitic coal, but all are lenticular. Some observers note great irregularity in the deposits, which appear to be fresh-water throughout.<sup>39</sup>

West from the 109th meridian, one approaches the mountain region and finds the whole Cretaceous exposed. In northern Fergus County, the Lance appears to be present, but the relations of the beds are not altogether clear. Near the Crazy Mountains in Meagher County, Stone found 1,200 to 2,800 feet of shales and sandstones, which he places in the Laramie; but the Lennep sandstone, at the base, 200 to 400 feet thick, is known now to be Fox Hills. Lenses of coal, a few inches thick and of insignificant horizontal extent, are present in the Laramie. Not far westward from this district shore conditions prevail and a continuous formation,

<sup>38</sup> E. G. Woodruff, Bull. 341, 1909, pp. 202, 205; Bull. 381, p. 173; C. W. Washburne, Bull. 341, pp. 167, 169, 181; C. H. Wegemann, Bull. 471-F, 1912, pp. 26, 30; D. E. Winchester, Bull. 471-F, p. 58; *Journ. Wash. Acad. Sci.*, Vol. VII., 1917, p. 36; N. H. Darton, Prof. Paper 65, 1909, p. 58.

<sup>39</sup> W. R. Calvert, C. F. Bowen, F. A. Herald, J. H. Hance, Bull. 471-D, 1912, pp. 13, 21, 48, 49, 91.

the Livingston, occupies the whole interval from near the base of the Pierre to the lower portion of the Fort Union.<sup>40</sup>

In Teton County, on the Canadian border and near the western boundary of the Cretaceous, Stebinger saw 980 feet of clay, clay shales soft gray to greenish gray cross-bedded and rippled sandstones with coal seams and some lenticular limestones. Apparently, the succession from Lower Cretaceous to the top of the Eocene is conformable throughout. This mass, placed by Stebinger at top of the Cretaceous column, is shown by tracing to be the St. Mary formation of Dawson in Alberta. Its sandstones contain fossil wood. Coal seams occur at top and near the bottom, but they are too thin and uncertain to be of economic importance. The persistence of a coal horizon near the base proved, as Stebinger observes, the existence of widespread though transient coal-forming conditions soon after deposition of the great Horsethief (Fox Hills) sandstone. The coal seams improve near the Canadian border.<sup>41</sup>

Passing over into Canada, Dawson in southeastern Alberta placed a great mass of deposits in the Laramie, but later studies have made evident that only the lower division should be referred to that formation. This, the St. Mary beds, is, at least in part, the same with the Edmonton of Dowling and with the Lance in Wyoming and Montana. The formation, about 2,800 feet thick, is of fresh-water origin except at the base and in its upper portion has sandstones which are cross-bedded, rippled and with worm borings.<sup>42</sup> Dowling<sup>43</sup> measured about 3,000 feet on Oldman River, mostly sandstone with sandy shales and some thin coals at the base. In the Sheep River district, two seams were seen near the Foothills, but farther east on Sheep River there is only one. Tyrrell<sup>44</sup> studied a large area in eastern Alberta between the Red Deer and North Saskatchewan Rivers. At the south near Red Deer River, he saw two important coal seams near the top of the formation, each about

<sup>40</sup> R. W. Stone, Bull. 341, pp. 82, 84; R. W. Stone and W. R. Calvert, *Econ. Geol.*, Vol. V., 1910, pp. 551-557, 652-669, 741-764.

<sup>41</sup> E. Stebinger, Bull. 621-K, 1916, pp. 124, 127, 128, 145.

<sup>42</sup> G. M. Dawson, Geol. Survey of Canada, Reps. Prog. 1882-83-84, Part C, pp. 36-72.

<sup>43</sup> D. B. Dowling, Summ. Reps. for 1903, pp. 142-149; the same, for 1914, p. 47.

<sup>44</sup> J. B. Tyrrell, Rep. Prog. for 1886, Part E, pp. 56, 60-63, 132.

10 feet thick; but he did not find them persistent. In the North Saskatchewan portion of the area, the important coal is also near the top of the formation. The chief seam was seen first near Wintering Hills as a bed of carbonaceous shale; but farther north it becomes coal and increases steadily until it becomes 25 feet thick. Several seams were seen in the lower portion of the formation, but the most persistent horizon is about 160 feet above the Pierre. Cross-bedded sandstone was observed at many localities.

About twenty-five years later, when the region had been opened up, Dowling<sup>45</sup> reported upon the Edmonton District, a portion of the area studied by Tyrrell. There he found about 700 feet of Laramie (Edmonton, St. Mary), a succession of shales and sands, too often merely clays and sands, a brackish-water formation between the marine Pierre and the fresh-water Pashkapoo of the Tertiary. It is rich in coal seams, which increase from south to north. The important coal horizon is near the top of the formation and it has been followed from the Red Deer to the Pembina River, becoming thicker toward the north and northwest. Three seams were seen on the Pembina, of which the highest is 26 feet thick; on the north Saskatchewan, a seam, belonging to the same coal group in the upper part of the formation, is 25 feet. Below the middle of the formation, Dowling saw another coal group; some of its seams are lenses of moderate extent, while others have been traced by borings under a considerable area; but they vary greatly in thickness and may be lenses. Dowling is evidently far from certain that the main seam of the region is persistent.

McConnell<sup>46</sup> states that the Laramie in northern Alberta has numerous seams of inferior lignite and ironstone. Rose reporting on the Lance of southwestern Saskatchewan, refers to the formation as a transition from the marine Fox Hills to the fresh-water Fort Union. The rocks are slightly consolidated and the seams of lignite are unimportant.

<sup>45</sup> D. B. Dowling, *Memoir 8-E*, 1910, pp. 13, 16, 18, 27, 28.

<sup>46</sup> R. G. McConnell, *Ann. Repts.*, Vol. VI.-D, 1893, p. 53; B. Rose, *Summ. Repts. for 1914*, pp. 64-67.

*The Fox Hills, Lennep Sandstone, Horsethief Sandstone.*

In this study the transition beds from the marine Pierre to the fresh-water Laramie are taken to be the Fox Hills. At very many localities, where the higher members of the Cretaceous have escaped erosion, this transition formation is a shore or offshore deposit of more or less coarse materials, with fossils, mostly marine but accompanied at times by brackish-water forms. Within some basins, coal seams of great economic importance are present, while in others, coal is wanting or in such small quantity as to possess only geological interest.

Reports on the San Juan Basin to which the writer has access, give no details sufficing to determine whether or not the Fox Hills is present in any considerable part of the Basin; but a section by J. H. Gardner, cited and discussed by Lee,<sup>47</sup> shows that it exists in the northern part. The Pictured Cliffs sandstone, 394 feet thick, mostly gray sandstone, contains marine fossils to the top. It underlies 79 feet of brackish to fresh-water beds, in which coal seams, 4 and 12 feet thick were seen at 4 and 57 feet from the base. Lee includes these in the "Laramie," as there appears to be uncertainty respecting the relations of some parts of the column. No coal has been reported from the Pictured Cliffs sandstone.

The existence of Fox Hills is equally uncertain in the Uinta Basin of western Colorado. Fox Hills conditions recurred at various horizons in the Pierre of this basin, as they did in central New Mexico, so that the earlier observers recognized both Fox Hills and Laramie in the Pierre beds. But there is no room for doubt that the formation exists in the southeast prong of the Colorado portion of the Green River Basin; for there Gale<sup>48</sup> found the basal sandstone of the "Laramie," resting on the Pierre, with a marine fauna. The thick coal bed at Craig apparently belongs in the Fox Hills. About 50 feet of this formation has escaped erosion in North Park, Colorado, where it rests on the great mass of Pierre shale. There Beekly obtained marine shells and the furoid *Halymenites major* from this sandstone; but no coal is present.<sup>49</sup>

<sup>47</sup> W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, pp. 587-591.

<sup>48</sup> H. S. Gale, *Bull.* 341, pp. 287, 295.

<sup>49</sup> A. L. Beekly, *Bull.* 596, 1915, p. 46.

The relations are sufficiently clear in the main portion of the Green River Basin with Wyoming. In Uinta County, the basal 200 feet of "Laramie" with alternating marine and land deposits includes among others the great Adaville-Lazeart coal seam, 10 to 84 feet thick; Veatch's brief summary of the coals gives no details respecting the accompanying rocks. Schultz found in the Rock Springs field of Sweetwater County a yellowish white sandstone at base of the "Laramie," overlain by sandstones, clays and coal beds; in some places fossils abound. The basal sandstone rests on the upper member of the Pierre. The coal of this Fox Hills is inferior and is no longer mined. Smith reports that in northeastern Carbon County, marine fossils are present up to 500 feet from the base of the "Laramie," which, he says, is a common condition in southern Wyoming and northern Colorado. Here as in other parts of the basin, a great sandstone is at the base. Coal is present in the Fox Hills, but the beds are unimportant, the thickest being only 18 inches. Veatch<sup>50</sup> separates the beds with marine fossils in east central Carbon from the Laramie and places the great white sandstone with its overlying beds in the Pierre. No occurrence of coal is noted. Ball and Stebinger in southern Carbon place the sandstone and the overlying beds in the Laramie, but state that marine fossils have been up to 400 feet above the sandstone. They give no details respecting the character of the beds and apparently they saw no coal.

The Raton-Trinidad coal field of New Mexico and Colorado is at the eastern foot of the Front Ranges. The earlier students regarded the coal-bearing rocks as conformable throughout and placed them in the Laramie. The numerous unconformities observed were thought to be merely local variations, characterizing deposits on the rudely level strand area. Lee, however, has proved that the irregularities are far greater than imagined by his predecessors and that a great unconformity by erosion separates the column into the Raton and Vermejo formations, the former most probably of Tertiary age. The Vermejo, resting on the Trinidad sandstone, is taken by the writer to be Fox Hills but Lee is inclined to regard it

<sup>50</sup> A. C. Veatch, Bull. 285, 1906, p. 333; Bull. 316, 1907, pp. 246, 248; E. E. Smith, Bull. 341, pp. 225, 228, 229; M. W. Ball and E. Stebinger, Bull. 341, pp. 246, 247; Bull. 381, 1910, p. 193.

as somewhat older. At the same time, in view of conditions farther north along the eastern foot of the Front Ranges, the writer feels compelled to abide by his opinion expressed 35 years ago, that in large part, at least, the rocks belong to the Fox Hills. The basal sandstone known now as the Trinidad sandstone (*Halymenites* sandstone of Stevenson), contains some marine fossils with great abundance of the fucoid, *Halymenites major*; the overlying beds, with extreme thickness of about 500 feet, are prevailingly sandstone with interbedded shales and coal seams. The rocks have fossil leaves, which are older than Laramie and a few marine fossils have been seen. The coal seams are numerous but are indefinite, varying so greatly in thickness and relative position that correlation, especially of the higher ones, is not possible. All are excessively variable in the New Mexico portion of the field, but some of them attain importance in modest areas and are mined extensively. In the northern or Colorado part of the field there are from one to 8 seams in the 250 feet above the Trinidad sandstone. This group is persistent and consists of lenses, which frequently are workable. Near Sopris, the seams "thicken and thin out characteristically," they are broken by partings and the coal is dirty. Near Trinidad, the coal is sometimes without a parting. The accompanying rocks are as variable as the coals. Near Pictou, 3 seams are mined. At the outcrop, the intervals are 15 and 30 feet; but at 2,500 feet in the mine, the upper and middle beds have united and the interval to the lower one is but 20 feet. The coal seams are not persistent and resin is found in the northern part of the field.

	I.	II.	III.	IV.	V.
Coal . . . . .	4 ft. 0 in.	0 ft. 8 in.	0 ft. 10 in.	4 ft. 0 in.	4 ft. 0 in.
Bone or shale.	0 ft. $\frac{3}{4}$ in.	7 ft. 0 in.	21 ft. 10 in.	24 ft. 0 in.	7 ft. 0 in.
Coal . . . . .	3 ft. 4 in.	1 ft. 8 in.	3 ft. 0 in.	5 ft. 0 in.	0 ft. 8 in.
Parting . . . . .	thin	0 ft. 2 in.	14 ft. 0 in.	13 ft. 0 in.	25 ft. 0 in.
Coal . . . . .	2 ft. 1 in.	5 ft. 0 in.	6 ft. 0 in.	9 ft. 0 in.	0 ft. 3 in.
Clay or shale.	1 ft. 4 in.	0 ft. 4 in.	8 ft. 0 in.	12 ft. 0 in.	22 ft. 5 in.
Coal . . . . .	0 ft. 10 in.	2 ft. 0 in.	1 ft. 0 in.	1 ft. 0 in.	blossom
Total . . . . .	11 ft. 7 in.	16 ft. 10 in.	54 ft. 8 in.	68 ft. 0 in.	58 ft. 11 in.
Total of coal	10 ft. 0 in.	9 ft. 4 in.	10 ft. 10 in.	19 ft. 0 in.	4 ft. 11 in.

On the northern side of the Raton plateau, a sandstone at 70 feet above the Trinidad coal bed, contains many weather-beaten tree

trunks along with worm borings and impression-like *Halymenites*. The extreme instability of conditions on the sandy flats, where coal accumulated, is shown by variations in the Trinidad coal bed, mined at Engle and Starkville. Stevenson's measurements are given in the preceding table.

These measurements are all within 3 miles from the first and the position to the Trinidad sandstone precludes all probability of error in correlation. The Trinidad sandstone is practically without coal.<sup>51</sup>

Fox Hills conditions are distinct farther north on the Arkansas River in the Canyon City coal field. Stevenson visited this field in 1873, but the movements of the party, to which he was attached, were so rapid as to give opportunity only for errors. He visited it again in 1881 and Washburne examined it in detail during 1908. These observers recognized the Trinidad sandstone, from which Stevenson, in both visits, obtained *Halymenites*. The Vermejo formation is about 500 feet thick, including the basal sandstone and its uppermost member is a massive sandstone, 145 feet, containing abundant *Halymenites*. According to Washburne, this member, nearer the mountains, loses its marine fossils, is less massive, is cross-bedded and has all the characteristics of a fluvial deposit.

The coal seams are numerous and some are important. One, resting on the Trinidad sandstone, is 3 ft. 4 inches thick with at times shale, at others, sandstone as the roof, the less thickness being under the sandstone. The shale is 0 to 7 feet thick, showing that the erosion followed deposition of the shale. Sandstone "rolls" were seen by Washburne in a bed about 275 feet above the Trinidad sandstone. These extend for long distances and the sandstone passes through the roof clay, often through the coal to the floor. These "rolls" have rounded bottom, curved sides and the trend is toward northeast throughout the mine. The current bedding in the "rolls" indicates a northeast flow for the streams. Resin occurs in the lowest coal seam.

Fox Hills has been recognized in the Denver Basin by Eldridge

<sup>51</sup> J. J. Stevenson, U. S. Geog. Expl. W. of 100th Mer., Vol. III., suppl., 1881, pp. 102 ff.; G. B. Richardson, Bull. 381, 1910, pp. 385, 386, 395, 411; W. T. Lee, Bull. Geol. Soc. Amer., Vol. 23, 1912, p. 611. It is unfortunate that Lee's elaborate report on the Raton coalfield is still unpublished.

and by Fenneman,<sup>52</sup> who assign to it a thickness of 800 to 1,200 feet. These observers recognized no coal in the Fox Hills, as they took the important coal seams of the basin to be Laramie. But Stevenson<sup>53</sup> saw coal in rocks of Fox Hills age at 5 miles southeast from Evans, about 40 miles north from Denver. From a sandstone overlying coal he obtained *Ammonites lobatus*, *Cardium speciosum*, *Mactra alta*, *Mactra warreniana*, *Lunatia moreauensis* and *Anchura*. The *Halymenites* is abundant.

The deposits in western Wyoming, which earlier observers termed Fox Hills, are known now to belong to the Pierre, but the formation is present in some areas. The "Laramie" in the north-eastern part of the Bighorn Basin, 150 to 700 feet thick, is apparently Fox Hills. It is mostly a massive sandstone but contains some seams of coal, occasionally workable though of quality inferior to that from older formations. East from Bighorn Mountains, the Fox Hills was recognized in the Lost Spring field by Winchester, in the Sussex field by Wegemann and in the Black Hills by Darton, but no coal is reported from any locality, except one, where Wegemann saw a deposit of "unusual variability in thickness and quality."<sup>54</sup>

The Fox Hills is known in northwestern Montana as the Horsethief sandstone described by Stebinger, as the Lennep sandstone of Stone and Calvert in the central part of the state. Stebinger traced the Horsethief sandstone across the Canadian boundary and proved its continuity with the Fox Hills of Dawson. He describes the sandstone as 360 feet thick, buff, coarse, massive and much cross-bedded in the upper half, but becoming slabby and more or less shaly toward the base. Usually the fauna is brackish, *Ostrea*, *Corbicula*, *Corbula*, and *Anomia*, but at some horizons it is marine of the litoral type, *Tancredia*, *Cardium* and *Mactra*. In his paper of 1914, he shows that the Horsethief sandstone was at one time continuous from the Teton district at eastern foot of the Rocky Mountains to

<sup>52</sup> G. H. Eldridge, Mon. 27, 1896, pp. 69, 72, 73; N. H. Fenneman, Bull. 265, 1905, p. 33.

<sup>53</sup> J. J. Stevenson, *Amer. Journ. Sci.*, Vol. XVII., 1879, pp. 369-372.

<sup>54</sup> C. W. Washburne, Bull. 341, p. 169; D. E. Winchester, Bull. 471-F, 1912, p. 58; C. H. Wegemann, the same, pp. 25, 32; N. H. Darton, Prof. Paper 65, 1909, p. 57.

the Black Hills on the Wyoming border. No coal, aside from some insignificant lenses, has been seen in this northern extension of the Fox Hills; and the conditions are the same in Alberta.<sup>55</sup>

### *The Pierre Formation.*

Thus far the tracing has been comparatively simple. The Laramie and Fox Hills mark the closing portion of the Cretaceous and conditions appear to have been much the same in each throughout the whole region. But during the Pierre, conditions near the source of sediments were wholly different from those in the great area beyond. On the eastern side, the rocks are almost wholly shale and without coal, while on the western and southern sides there are great deposits of sandstone and sandy shale with, in some areas, important coal seams at several horizons. At the east, the fossils are marine but at the west and south there are marine and brackish as well as fresh-water horizons. The offshore and strand conditions, marking strife between advancing land and the sea, are evident from the recurrence of a fauna allied to that of the Fox Hills as well as of sections showing a succession like that of Fox Hills and Laramie, a gradual transition from marine to continental deposits. In the description of widely separated areas, local terms based on lithological features became necessary, but the resulting confusion has been removed by the labors of the students listed on an earlier page and the relations are now well understood, though in some areas there still remains uncertainty as to the planes of separation.

In Alberta, Montana and northern Wyoming the Pierre is divided into Lewis or Bearpaw shale, Judith River formation, Claggett shale and Eagle sandstone: the last, overlying shale. This order, descending, is distinct from the Bighorn Basin of Wyoming northward into Alberta, but, at a short distance westward, where one approaches the western limit of Cretaceous deposition, some modifications in nomenclature and grouping become necessary. Farther south in Wyoming, Colorado and New Mexico, the succession is given as Lewis shale, Mesaverde formation and Mancos shale. The term, Mesaverde, is indefinite; it is the sandstone member of the Pierre and is more or less coal-bearing. In some extensive areas it

<sup>55</sup> E. Stebinger, Bull. 621-K, 1916, p. 125; Prof. Paper 90-G, p. 62.

embraces practically the whole of the Pierre, while in others it but the middle portion. Mancos is another lithological term, designating the mass of shale underlying the Mesaverde, so that in many districts it includes the Lower Pierre as well as the Niobrara and Benton. The significance of the several terms will appear in description of the districts.

The Pierre in the Parks of Colorado and east from the meridian of the Front Ranges of Colorado consists mostly of shales, becoming sandy toward the top, with irregular lenses of limestone and, in the upper portion, huge calcareous and ferruginous concretions. Sandstone is wholly unimportant except in the Boulder district of the Denver Basin, where Fenneman saw,<sup>56</sup> at one third way from the base, the Hygiene sandstone, which is several hundred feet thick west from Berthoud, but only 250 feet at the north end of the district. The thickness of Pierre in this region is not fully determined; Eldridge gives 7,700 to 7,900 feet in the Denver Basin, but Fenneman gives only 5,000 in the Boulder district of that basin. Near Canyon City on the Arkansas River, oil-borings found 4,500 feet, while farther south on the eastern border of the Raton-Trinidad coal field, the thickness appears to be considerably less.

But the change is startling between the southern termination of the Raton field and Cerillos, a distance of about 100 miles in west of south direction. At Cerillos, one is on the same meridian with the Park area of Colorado, where the Pierre is almost wholly shale, whereas here it is largely sandstone. Some small isolated coal fields remain farther south. The Engle, unimportant from the economic standpoint, has coal-bearing rocks, which as Lee<sup>57</sup> has shown, rest on deposits of Benton age. Wegemann found similar conditions in the Sierra Blanca field about 80 miles west-northwest from the last. Both authors are inclined to refer the coals and associated rocks to the Mesaverde, because the general conditions resemble those observed farther north in the Cerillos field. In the absence of conclusive information, the writer is inclined to suggest that the coals may be of Benton age. The Sierra Blanca area is not far from 120 miles south from the Cerillos field and by so much

<sup>56</sup> N. M. Fenneman, Bull. 265, 1905, pp. 31, 32.

<sup>57</sup> W. T. Lee, Bull. 285, 1905, p. 240; C. H. Wegemann, Bull. 541-J, p. 10.

nearer the source of sediment. One should expect to find in that direction the same conditions as appear on the western border, where important coals occur in the Benton.

The Cerillos coal field, a few miles south from Santa Fe, New Mexico, has been examined by several geologists whose conclusions are not in agreement.<sup>58</sup> Stevenson thought that the coal-bearing group belongs to the Laramie; Johnson referred it to the Fox Hills; but Lee recognized the true relations and determined that it is Mesaverde, the Middle Pierre in this field. The coal group is about 1,200 feet thick and rests on Mancos shale, of which the top 150 feet carries Pierre fossils. The basal rock of the coal group is a sandstone, 300 feet thick and without coal. It has an assemblage of fossils which suggests Fox Hills conditions. The coal seams are numerous but variable. The sections of one bed at four openings, as given by Stevenson, are

Coal .....	1 ft. 2 in.	Thin	Streaks	Absent
Clay .....	1 ft. 3 in.	6 ft. 0 in.	12 ft. 0 in.	8-10 ft.
Coal .....	2 ft. 3 in.	2 ft. 5 in.	4 ft. 7 in.	3 ft. 10 in.
Coaly shale ....	3 ft. 5 in.	Absent	Absent	1 ft.

In one mine the coal has been replaced with sandstone in a space 75 feet wide and several hundred feet long, a case of contemporaneous erosion. Gardner<sup>59</sup> saw an apparently similar replacement in the Omera field, east from Cerillos. At 500 feet from the outcrop in a mine, the roof descended and cut out the coal. In 1879, Stevenson noted a ripple-marked sandstone and an underclay with roots.

The only information available for present purposes, respecting coal fields between Cerillos and the great San Juan Basin at the west, is contained in Lee's publications.<sup>60</sup> The Hagan field directly west from the Cerillos differs notably from the latter. The most striking difference is due to increase of Mesaverde at expense of the

<sup>58</sup> J. J. Stevenson, *U. S. Geog. Expl. W. of 100th Mer.*, Vol. III., Suppl., pp. 147 ff.; *N. Y. Acad. Sci.*, Vol. XV., 1896, pp. 105 ff.; D. W. Johnson, *Sch. Mines Quart.*, Vols. XXIV., XXV., 1903; W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 642, 658; *Bull. 531-J*, 1913; Prof. Paper 95-C, 1915, p. 41.

<sup>59</sup> J. H. Gardner, *Bull. 381*, 1910, p. 448.

<sup>60</sup> W. T. Lee, *Bull. 389*, 1909, pp. 5-40; *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 622-642.

underlying Mancos. The lower portion of Mesaverde in Cerillos is the great sandstone, 300 feet thick; but in Hagan it is about 900 feet, mostly sandstone, without coal and with Pierre fossils at several horizons. The coal group immediately overlying it is 180 feet thick with 5 coal seams, of which one has local importance. This averages about 3 feet in a small area and underlies a massive coarse sandstone, cross-bedded and containing petrified wood. Thin streaks of coal were seen in higher parts of the column. The whole thickness is about 1,850 feet and the upper half has no marine fossils. The Tijeras coal field, at 25 miles southwest, gives clearer evidence of land conditions. The lower portion of the Mesaverde is only 700 feet thick, but it contains 3 coal beds, 2 inches to 3 feet thick, proof that the broad sand flats were free from sea-invasion long enough to permit accumulation of peat in the hollows of their irregular surface. The lithology changes above the uppermost marine sandstone. Exposures are such as to make measurements indefinite, but the presence of what the writer takes to be the Cerillos coal group is distinct, for two coal seams, 3 feet and 1 foot 6 inches, were seen. This upper portion contains no marine forms. The basal deposit is a massive sandstone, 115 feet thick.

The Rio Puerco field, beyond the Rio Grande, is about 25 miles west from Hagan and Tijeras. Lee gives 1,700 feet as the thickness of Mesaverde, but thinks that the upper part has been removed by erosion. The Mancos (Colorado) shales are but 1,113 feet, whereas they are 2,350 feet at Cerillos. The Mesaverde has many horizons of marine fossils even to the top; but, at about 300 feet from the top as here exposed, it has a coal group, 185 feet, with 16 coal seams, all very thin; and another, about 100 feet thick, with one of the beds 6 feet thick, at 450 lower. Some of the sandstones contain fossil leaves in abundance. At the base is a massive marine sandstone, the Punta de la Mesa sandstone of Herrick and Johnson,<sup>61</sup> which is 77 feet thick. The former existence of another coal-bearing group is shown at the top of the column, where Lee found at some localities a shale with thin coal. At the same time it seems probable that the upper coal group represents that at Cerillos. Lee's suggestion that the 300 feet of marine sandstone and sandy shale at

<sup>61</sup> C. L. Herrick and D. W. Johnson, *Bull. Univ. New Mex.*, Vol. II., p. 6.

the top of the section may represent the Lewis shale is very far from improbable: there appears to be good reason for believing that the Mesaverde of Rio Puerco includes the whole of the Pierre, whereas at Cerillos, Mesaverde is Middle Pierre.

Pierre deposits are exposed on the borders of the great San Juan Basin. Information is lacking for the southern prong of this basin but is fairly abundant for the main part, northward from Lat.  $35^{\circ} 30'$ , though comparatively few details have been published. Gilbert,<sup>62</sup> during the reconnaissance in 1873, measured a long section of Cretaceous at Stinking Spring, 12 miles west from Fort Wingate in New Mexico. This shows about 700 feet of yellow shales, yellow sandstones with coal beds, resting on 1,050 feet of sandstones and mostly sandy shales. Of the 7 coal seams, 3 reach workable thickness; one of them is triple, the benches being 4, 5 and 2 feet, separated by 5 feet and one foot of shale. There is no coal in the basal 200 feet. The Cretaceous in this region is one lithologically; "characterized by sands, by coal, by rapid alternations, by ripplemarks and by oysters, it is evidently an off-shore deposit." But fossils offer basis for subdivision; they are abundant in the lower 850 feet, which may be taken here as representing the shore facies of Colorado or lower portion of the Mancos, as that appears in the type locality.

Thirty years later, Schrader<sup>63</sup> made a reconnaissance of the eastern side of the basin, from Gallup, near Fort Wingate, to the northern border in Colorado. The section is longer than at Stinking Spring and during the 30 years interval the coal bed had become important. He found shales and sandstones, 2,000 to 3,000 feet thick, with the Upper Coal Group in the lower part; shales and sandstones, 500 to 800 feet, with the Middle Coal Group near the top; and 500 to 1,000 feet of Colorado shale, with the Lower Coal Group near the top. The Upper Coal Group is about 100 feet thick and contains 6 workable coal seams, 5 of which have fireclay floors. The Middle Coal Group appears to be the same with that of Gilbert's section. The coal seams throughout appear to be irregular.

<sup>62</sup> G. K. Gilbert, U. S. Geog. Explor. W. of 100th Mer., Vol. III., 1875, pp. 544, 549, 550.

<sup>63</sup> F. C. Schrader, Bull. 285, 1906, pp. 242, 254, 255.

Gardner<sup>64</sup> afterwards examined this line more in detail. Here he regarded the upper and middle groups of Schrader as Mesaverde (here evidently in part Lower Pierre), to which he assigns a thickness of about 1,000 feet east from Gallup. The coal seams are numerous but variable; "within a few miles, thin beds undoubtedly thicken to valuable properties and thicker beds thin to mere traces."

Farther north between San Mateo and Cuba, the Mesaverde, 1,200 feet thick, is coal-bearing throughout. Near the top is the first appearance of the Lewis shale, which contains much sandstone and sandy shale. There, one is little more than 40 miles northwest from the Rio Puerco locality, where Lee found marine fossils at top of the Mesaverde and thought that the deposits might be the equivalent of Lewis shale. No trace of that shale is reported from any locality farther south in the San Juan Basin. Along this portion of the outcrop, the Mesaverde coal seams are in two groups, separated by 300 feet of barren measures; the seams are all lenticular and in several instances have bony coal at top or bottom or both. Gardner's observations north and west from Cuba are important. At a little north from Gallina, 14 miles north from Cuba, the Lewis is 2,000 feet while westward it becomes only 250 near Raton Spring. Gardner thinks this westward change due to replacement with sandstone, which has been regarded as Mesaverde. The condition southeast from Cuba confirms the suggestion, for there the Mesaverde is but 719 feet, with no coal in the basal 300 feet and only coaly shale or thin coals at widely separated horizons in the upper part. The thinning is more notable beyond Gallina, where the Mesaverde is but 214 feet and contains 14 coal seams, of which only one is of workable thickness. The coal is subbituminous, occasionally resinous and the seams are variable to the last degree. The Mesaverde is limited, top and bottom, by massive sandstones which persist although the section is decreased. Lee<sup>65</sup> states that Gardner's collections from Lewis shale and from Mesaverde south and southeast from Cuba, are marine. He saw great numbers of petrified stumps and logs in the lower part of the Mesaverde near Cabezon, where the upper part of the Mancos has Pierre fossils.

<sup>64</sup> J. H. Gardner, *Bull.* 341, 1909, pp. 339, 343, 345, 366, 372, 377; *Bull.* 381, 1910, pp. 463, 470.

<sup>65</sup> W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 619-621.

It would appear from the observations by Lee and Gardner that, in this portion of the basin, the Mesaverde is again Middle Pierre. The sea area extended as a gulf southward as far as Cabezon's latitude and the sandy member of the Pierre must have disappeared at only a little way east from Gallina.

Shaler<sup>66</sup> examined the western outcrop in the San Juan Basin. He reports that Lewis shale, only 250 feet thick where first recognized at the south, becomes 2,000 feet farther north but diminishes to 1,600 feet at the northern outcrop. The Mesaverde, massive sandstone and thin interbedded shales and sandstones with coal seams at the south, shows the triple succession at the north, where the thickness is from 750 to 1,450 feet. He observed "horsebacks" and "rolls" in a Mesaverde seam near Gallup. Along the northern outcrop in Colorado, Cross and Spencer<sup>67</sup> found the highest member of the Pierre, named by them the Lewis shale, well defined. The Mesaverde, named by W. H. Holmes, is triple, the two great escarpment sandstones with between them a coal group of sandstones, marls and coal seams. The whole thickness in the La Plata quadrangle is barely 1,000 feet, that of the coal group being 600. The coal seams are variable and the authors look upon them as a series of lenses. The Mancos shale named by Cross, has Pierre fossils in the upper "several hundred feet," so that here also, one has the condition observed on the opposite side of the area, at Cerillos, where Mesaverde is the Middle Pierre. In the southern part of the San Juan Basin, it would appear that Mesaverde and Pierre are practically synonymous terms. Gardner's<sup>68</sup> observations are of interest in this connection. He traced the Mesaverde around the northern border from Durango, Colorado, to Monero, New Mexico. It is about 1,000 feet thick near Durango but decreases eastwardly, so that it is only 400 feet at the Piedra River, 60 miles from Durango. This is in accord with Schrader's observations and with those of Gardner in the Gallina area. One seems to be justified in suggesting that the Mesaverde disappears at a short distance east from the San Juan basin, giving place to the shales, which are present in

<sup>66</sup> M. K. Shaler, Bull. 316, Part 2, 1907, pp. 378, 414.

<sup>67</sup> W. Cross, "Telluride Folio, No. 57," 1899; W. Cross and A. C. Spencer, "La Plata Folio, No. 60," 1899.

<sup>68</sup> J. H. Gardner, Bull. 341, p. 353.

Colorado on both sides of the Front Ranges. Near Durango, three workable coal seams are present within a vertical distance of 110 feet, midway in the Mesaverde; these become insignificant toward the east and no workable seam was seen along the outcrop for more than 60 miles. But at Monero in New Mexico, three seams of workable thickness are present in a vertical distance of 100 feet above the basal sandstone.

The Uinta Basin extends from the westerly foot of the Wasatch Mountains in Utah into northwestern Colorado and has an area of not far from 10,000 square miles, being a little larger than the San Juan Basin. The Utah prong, known as Castle Valley, was examined by Taff and by Lupton, while Gilbert has given the section in the Henry Mountains about 50 miles southeast.<sup>69</sup> The highest Cretaceous beds in the Henry Mountains are the Masuk sandstone and Masuk shale of Gilbert, the former containing coal seams; it is thought by Lupton to be most probably Mesaverde. Lupton made no detailed study of the Mesaverde in Castle Valley, but estimated the thickness as not far from 1,200 feet and notes that it contains several important coal beds in a section of 500 feet, beginning at 200 to 300 feet from the base. Taff notes the triple structure of the Mesaverde, the two sandstones separated by the coal group. The coals are numerous but are important only in the lower 250 feet of the group. The coal is massive, bright, clean, bituminous and contains much resin. Partings are usually insignificant, but Taff saw one in a thick coal seam, which increased from nothing to 16 feet within 2,000 feet. The roof and floor of the coal seams are often sandstone.

Richardson examined the southern side of the basin between Sunnyside, Utah, and Grand River, Colorado, known as the Book Cliffs coal field.<sup>70</sup> The thickness of the Mesaverde is given as 1,200 to 2,200 feet, the variation being due to erosion. The underlying Mancos shale contains Pierre fossils in the upper 250 feet and is nonfossiliferous for a great thickness below; so that the Mesaverde is not lower than Middle Pierre. The sandstones of the formation

<sup>69</sup> G. K. Gilbert, "Geology of the Henry Mountains," U. S. Geog. and Geol. Survey of the Rocky Mountain Region, 1877, pp. 4-10; J. A. Taff, *Bull.* 285, 1906, pp. 292-294, 298; C. T. Lupton, *Bull.* 628, 1916, p. 34.

<sup>70</sup> G. B. Richardson, *Bull.* 371, 1909, pp. 7-39.

are lenses and are the marked features of the Book Cliffs; the lower members contain *Halymenites major* and brackish-water forms are present at many horizons. The coal seams of economic importance are confined to the lower 700 feet but Richardson's section makes clear that the importance in each case is confined to a small area and that the seams must be lenses. Near Thompson, Utah, at the southern point of the field, there are 5 seams, beginning at 490 feet from the base; near Price canyon farther north, are 7 beds, beginning at 340 feet, while near the Colorado line 6 seams were seen in the basal 275 feet, the lowest being only 95 feet from the bottom. On the Grand River the section shows 10 seams in the lower 519 feet. No coal seam has been traced for more than a few miles; one, 21 feet 6 inches thick, where mined, proved to be a mere lens, which disappeared quickly toward the west. Seams important at the east disappear toward the west. There are coal horizons, not continuous beds.

The Grand Mesa coal field and smaller fields farther east have been discussed by Lee,<sup>71</sup> who has made the relations clear for the region east from Grand River. The Upper Mancos is rich in Pierre fossils and the Mesaverde is 600 to 2,500 feet thick, the variation being due to erosion preceding deposition of newer formations. The upper part or undifferentiated Mesaverde, about 2,000 feet thick, is of fresh-water origin, mostly sandstone and contains little coal. It rests on the Paonia shale, closely allied to it lithologically, and about 400 feet thick. This has plant remains, fresh-water mollusks and important coal beds. Underlying this and separated from it in a considerable area by an unconformity, are the Bowie shales, 0 to 425 feet thick, with important coal seams and brackish-water as well as marine invertebrates. The basal deposit is the Rollins sandstone, usually about 100 feet thick, white, massive, with *Halymenites major* and marine invertebrates—evidently the basal white sandstone observed by Richardson in the Book Cliffs field.

Lee recognized a distinct unconformity below the Paonia; ordinarily, that formation rests on the Bowie, but for a considerable space in one portion of the region it overlies the Rollins. This leads

<sup>71</sup> W. T. Lee, Bull. 510, 1912, pp. 19, 37, 45, 81, 82, 86, 92, 95, 98, 106-109, 182, 188.

him to suspect that the unconformity may indicate a time interval and that possibly the Paonia and overlying rocks may not be older than Laramie. The unconformity is distinct, for the Bowie decreases from 425 feet on Grand River to nothing in the Rollins district; and it seems to be suggested on Grand River by the irregular contact between Paonia and Bowie at Palisades. It may be injudicious, it may savor of temerity for one who has not visited the localities to controvert the opinion of one who has examined the area in detail, especially when the latter is a model of accuracy in observation and caution in conclusion, but the writer feels compelled to believe another explanation not improbable. The vast area of Cretaceous deposition was subsiding until certainly toward the close of the Cretaceous as was the Appalachian Basin during Coal Measures time: but there were local crumplings as there were in the Appalachian. In the latter, these have left their records in deep stream valleys, filled with later deposits. Similar conditions have been observed in the British coal fields. It would be strange if evidences of local elevations or depressions were wanting in the vast subsiding Cretaceous region. The irregular contact on Grand River seems to indicate change in direction of drainage on the broad plain.

A serious argument in favor of assigning Laramie age to the Paonia and overlying deposits is the presence of a flora, which is described as containing Montana Laramie and even Post-Laramie forms, the Montana forms being few. The origin of a flora is a perplexing problem, but there seems to be no reason to suppose that it sprang into existence full-formed and without local forerunners, probably at many places. But, be that as it may, the Bowie and the Paonia appear to be continuous in the eastern part of the region described by Lee and no plane of separation has been determined. Farther north, just beyond the existing limits of the Uinta Basin, the Lewis shale has been recognized. It seems not unreasonable to suggest that in the southern part of this basin as in the southern part of the San Juan Basin, fresh-water sandstones may hold the place of the Lewis. The doubts must be dispelled by stratigraphy. The "Fox Hills" and "Laramie" of the earlier students have been placed in the Pierre, in spite of the remarkable resemblance to the later

formations. If the deposits under consideration underlie the Lewis, they belong to the Pierre.

The undifferentiated Mesaverde on the western border of Lee's area consists chiefly of massive cliff-making sandstones, about 1,500 feet thick, containing deciduous and conifer leaves as well as *Sphærium*, *Physa* and *Goniobasis*. Within 22 miles eastward, of about 1,000 feet exposed, 700 feet are shales; it may be described as shale with thick partings of sandstone, while near Bowie in the Somerset district the shale feature becomes much more marked; but in Crested Butte district, the southeastern part of the basin, it consists of sandstones separated by layers of shale. The coal seams throughout are thin.

The Paonia shales, at several horizons, are rich in fossil leaves and fresh-water mollusks. The lowest coal seam, Cameo of Richardson, is at 4 to 10 feet above the great sandstone at top of the Bowie; in the western part of the area studied by Lee, this coal horizon seems to persist throughout the whole region. This coal is double at Rollins, 3 and 11 feet with parting of 2 feet. Thin seams are at 80, 123 and 219 feet higher at Cameo on Grand River; but in the Rollins district 3 workable seams were seen in 108 feet above the base. Similar irregularity was observed in the easterly districts, so that one must look upon the coal seams as lenses. The quality is as variable as the quantity of coal. In one mine on the lowest seam, irregular masses of white sandstone descend from the roof and occasionally extend across the bed. Cross-bedded sandstone was seen midway in the section at several localities.

The Bowie shale, 420 feet thick on Grand River, has a sandstone, 100 feet, on top, cross-bedded, with worm tubes and *Halymenites*. Only one coal seam is there, about 430 feet below the Cameo bed; this is unimportant and thins away toward the south. There is no Bowie in the Rollins district, but it reappears farther east in the Somerset district, where, near Bowie, it is 405 feet and has the great top sandstone. The coal seams are numerous and at least 7 of them are "relatively thick," aggregating 38 to 43 feet in this district. The thickness of other seams has not been determined. The coals are exceedingly variable and they may be only extensive lenses; but some of them attain notable thickness. The Juanita bed is 12

feet in one mine near Bowie but 21 in another and 22 near Somerset ; while at another locality, no trace of it could be found. At the Johnson prospect, on Minnesota creek, east from Paonia, 9 coal seams, 2 to 8 feet thick and with total thickness of 43 feet, were seen in the lower 300 feet of the Bowie. At the Simonton prospect, about 4 miles toward the south, the exposure shows this section, beginning at 37 feet above the Rollins sandstone: coal, 2 feet, 10 inches; shale, 10 inches; coal, 1 foot, 2 inches; shale, 5 inches; coal, 13 feet, 1 inch; shale, 6 feet; coal, 16 feet; bony coal, 2 feet; coal, 7 feet, 2 inches; in all 49 feet, 6 inches.

The presence of this great mass is perplexing. One cannot trace the section from the Johnson prospect and Lee concludes that the Simonton seam is due to the coalescence of 7 seams of the Johnson section, or that it is a merely local deposit. The Bowie becomes irregular in districts farther east, sometimes present, sometimes absent, and the coals are extremely variable in thickness and quality.

Lee's notes show that mineral charcoal is present in most of the coals. Toward the Elk Mountains, the region is greatly disturbed by plication and by eruptive rocks; the coal is from subbituminous to hard dry anthracite. The seams are thicker on anticlines than in synclines. In some localities, the stream channels, due to contemporaneous erosion, have been filled with white sandstone.

On the northwestern side of the Uinta Basin, there is a mass of deposits, 0 to 3,300 feet thick, which Lupton<sup>72</sup> places in the Mesa-verde—the variation in thickness being due to erosion prior to deposition of the Wasatch beds. The lower half in this Blacktail Mountain coal field is marine, without coal and is mostly sandstone with sandy shale and some limestones. The upper half, apparently fresh-water, has coal with sandstones, thin-bedded and cross-bedded, as well as much sandy shale. This upper division has 21 coal seams in 1,500 feet, 7 inches to 15 feet thick. One seam has a maximum thickness of 21 feet with only a single parting, 2 inches. The coal is resinous at some places.

Gale<sup>73</sup> has given some notes respecting the northern outcrop. He reports the Lewis shale as about 1,000 feet thick and without

<sup>72</sup> C. T. Lupton, Bull. 471-I, 1912, pp. 27, 32, 33, 39, 41.

<sup>73</sup> H. S. Gale, Bull. 341, 1909, pp. 287, 289, 290, 299; Bull. 316, 1907, p. 273.

sandstone. The Mesaverde, 5,000 feet at the east, where erosion was less energetic, has three coal groups. The lowest is in the basal part of the formation and underlies a conspicuous white sandstone, which contains marine fossils. Gale's description suggests that this sandstone may be equivalent to the Rollins of Lee and that the lowest coal group may be in the Lower Pierre, included farther south in the Mancos shale. The coal seams are usually thin and where thick are worthless. The middle coal group, above the white sandstone, is unimportant west from the Utah line, but the seams become thicker toward the east, though they are irregular and at times are broken badly by partings of shale or bone. They become important in the eastern part of the basin; at Newcastle, there are 105 to 108 feet of coal in 7 seams, the thicknesses being 5, 8, 20, 5, 45-48, 18 and 4 feet respectively. One seam at Newcastle has a parting of soft coal at 4 to 6 feet from the floor and is troubled by "sandstone dikes." A seam at 40 miles south from Glenwood Springs has 7 to 10 feet of coking coal as the upper bench, but the lower bench is non-coking. The upper coal group is near the top of the Mesaverde; its coals are unimportant.

The Green River Basin, north from the Uinta Mountains, is mostly in Wyoming but the southeastern prong extends into Colorado and an outlier remains in Utah at the west.

The relations of the upper part of the long section in the Coalville coal field in Utah appear somewhat uncertain. The area was studied by Taff and later by Wegemann, the paleontological determinations being made by Stanton.<sup>74</sup> The boundaries of the several formations are still indefinite, but it is sufficiently clear that the region was near the source of sediment, for sandstone and sandy shale predominate in the upper 7,000 feet of the section. The upper 2,500 feet, prevailingly sandy, has yielded leaves and fresh-water shells. The succeeding 1,650 feet contains marine shells and rests on a white sandstone, 200 feet; below that is a coal seam. This, at 4,450 feet below the top of the Cretaceous, is irregular in occurrence as well as in its relations to the thick sandstones above and below it. It is double or triple at many localities, while at others

<sup>74</sup> T. W. Stanton, Bull. 106, 1893; J. A. Taff, Bull. 285, 1906, pp. 285-288; C. H. Wegemann, Bull. 581-E, 1915, pp. 163, 182.

it could not be found. At one locality, a seam belonging at or near to this Dry Hollow horizon underlies a bed of oyster shells, 20 feet thick. The quality of the Dry Hollow coal is good, but the bed is too variable, so that no mines of any importance were in operation at the time of Wegemann's examinations.

No coal of economic importance has been reported from the Pierre of Uinta County in Wyoming, but in southern Sweetwater County, where Gale<sup>75</sup> recognized Lewis, Mesaverde and Mancos, he saw in one exposure two seams, 8 and 10 feet thick, separated by only 25 feet. The coal is not persistent and, within a short distance, it becomes black shale with coaly streaks. The lower seam is separated by one foot of bone from a thick white sandstone. Farther north in the same county is the Rock Springs coal field, intersected by the Union Pacific Railroad. There Schultz<sup>76</sup> recognized the Lewis shale, without coal, and the Mesaverde, consisting very largely of sandstone with important coal seams. The "Laramie" of Schultz is not everywhere conformable to the underlying Pierre. The unconformity is especially marked on the south and west sides of the Rock Springs Dome, where the "Laramie" rests on the Rock Springs coal group, a hiatus of fully 2,500 feet; but the succession is complete and conformable throughout on the west side of the Dome. Elsewhere there appears to be no unconformity.

The important coal seams are in the Almond and Rock Springs groups, separated by 800 to 1,000 feet of mostly massive sandstone, more or less conglomerate in the upper third with pebbles of gray and black quartz. The Almond coal group, 700 to 900 feet thick, contains many seams of coal and of carbonaceous shale. The seams are variable, though less so than are those in the Rock Springs group, but the coal is comparatively poor and no works were in operation at the time of Schultz's examination.

The coals of the lower or Rock Springs group are black, with distinct bedding planes and do not slack on exposure. The coal-bearing portion is about 1,275 feet with 37 seams containing in all somewhat more than 110 feet of coal. Five seams have been opened

<sup>75</sup> H. S. Gale, Bull. 341, pp. 310-314.

<sup>76</sup> A. R. Schultz, Bull. 341, pp. 256-382; Bull. 381, pp. 214-281.

near Rock Springs, but most of the coal has been taken from numbers 1 and 7, at 481 and 743 feet from the top of the group.

Number 1 has many "rock-slips" or "horsebacks," long, slim wedges of white sandstone, protruding usually from the floor. They are smooth on one side, rough on the other and the coal is unchanged even at the contact. The roof and floor are brownish to white sandstone. The coal, at times, is 10 feet thick, but changes are abrupt. Partings thicken and the coal becomes worthless. In one mine the coal is 11 feet thick and clean, but in another, adjoining, the coal suddenly became worthless and, at a little distance beyond, it pinched out. Seam 3 shows similar complications. A band of shale appeared in one mine at 2 feet from the floor; within a short distance it thickened upward until the top bench became too thin for working; but within 200 feet the foreign matter almost disappeared and the upper bench was again more than 5 feet thick. Schultz's description shows that here is a channel originating during growth of the swamp and filled up before the growth ceased, so that the swamp covered it. Seam 7 is less inconstant than the others but it is far from free from troubles. The roof and floor are shale, the former black. One important mine was abandoned because the good coal was replaced with worthless stuff in an area of evidently great extent. The Rock Springs coal seams become unimportant southwardly and none has been discovered in the extreme southern portion of the field.

Tertiary deposits conceal the Cretaceous from the Rock Springs field to near Rawlins in Carbon County, where Smith<sup>77</sup> recognized the Lewis, Mesaverde and the shales of Lower Pierre. The Mesaverde, consisting of sandstones, shales and coal seams, is still distinct but is much thinner than in fields farther west. It consists of two massive sandstones separated by a mass of soft brown sandstones and white to gray shale. The Almond and Rock Springs coal groups have become insignificant. The coal seams in this area are on top and at base of the upper sandstone and just above the lower sandstone: four or more seams were seen in the upper zone, few were observed in the middle and 4 to 6 in the lower zone. The

<sup>77</sup> E. E. Smith, Bull. 341, pp. 220-242.

coal throughout is inferior and the seams, for the most part, are too thin to be mined.

Beyond Rawlins and still north from the Union Pacific Railroad, Veatch<sup>78</sup> studied the coal field of east-central Carbon County, where the Pierre consists of Lewis, Mesaverde and Lower Pierre, with a total thickness of almost 8,000 feet, not far from that given by Smith; but in both districts the thickness decreases greatly toward the north. According to Veatch, some important coal seams are present in the lower part of the Lewis, evidently those belonging to the highest zone of Smith. Seams in the middle zone of the Mesaverde occasionally become thick enough for mining, but they are irregular and not persistent. The southern part of Carbon County, where the subdivisions of the Pierre are as in the northern part of the county, was studied by Ball and Stebinger.<sup>79</sup> The thickness of Lewis and Mesaverde decreases eastwardly, becoming 1,600 and 2,000 feet. The Lewis has no coal. The Mesaverde still has the two limiting sandstones with the middle shale and sandstone member. The basal sandstone is white gray and brown, cross-bedded and, in the eastern part of the district, contains a limestone, 25 feet thick. The top sandstone is less distinctly cross-bedded and the layers are thinner. No workable coal seams were seen in the sandstone members, at the north, but the number and thickness of those in the upper sandstone increase toward the south. Some important seams are in the middle member near Rawlins, but they disappear toward the northeast. The coal is hard and bituminous. The sandstones of this member are irregular and the coal seams appear to be overlapping lenses.

The Yampa coal field, in Routt County of Colorado, is the extreme southeast part of the basin. One can recognize in the section by Fennemann and Gale,<sup>80</sup> Lewis, Mesaverde and the lower shales, Mesaverde being Middle Pierre; the relations are more allied to those of the western than to those of the northern part of the basin. There are three coal groups, which in some portions of the field are in a vertical space of 2,000 feet, the lowest being about

<sup>78</sup> A. C. Veatch, Bull. 316, 1907, pp. 244-366.

<sup>79</sup> M. W. Ball and E. Stebinger, Bull. 341, pp. 243-355; Bull. 381, pp. 186-213.

<sup>80</sup> N. M. Fenneman and H. S. Gale, Bull. 285, 1906, pp. 226-239.

1,200 feet from the base. Each coal group has 2 to 3 workable coal seams, but the number and thickness of the seams vary from place to place. At the time when this field was examined, the population was sparse and none but insignificant mines had been opened. In the eastern part, coal seams, 4 to 10 feet thick, were exposed in both the middle and the lower group; but the upper group is ill-exposed. Farther west, seams of greater thickness were seen, one near Lay being 20 feet, with a parting of 15 inches midway. There, the three coal groups are in a vertical space of not more than 800 feet. Many seams have shale roof and floor and one is clearly between sandstones. A faux-toit was seen in many openings and either bone or dirty coal is the usual parting. A faux-mur is recorded in but one instance.

The irregularity in thickness of the Mesaverde in the Yampa field may be due to the eastward disappearance of shore conditions. At 25 miles east from the boundary of the Yampa field, Beekly's<sup>81</sup> sections on the west side of North Park show no evidence of Mesaverde, while at 25 miles farther east in the same Park, the Pierre is represented by about 4,500 feet of shale, wholly like that beyond the Front Ranges in Colorado and New Mexico. It is sandy on top and passes into a marine sandstone, shown on east side of the Park—apparently the Fox Hills. Some thin sandstones were seen in the lower part of the formation but no trace of coal is reported by Beekly.

Northward in Wyoming and east from the Medicine Bow Mountains about 60 miles east of north from the exposures in North Park, the section by C. E. Siebenthal, cited by Darton,<sup>82</sup> shows about 5,500 feet of Montana rocks, divided at about 1,300 feet from the top by the Pine Ridge sandstone, 60 to 80 feet thick. The mass is practically shale throughout, there being in all only 127 feet of sandstone in the upper 1,332 feet and 35 feet in the underlying 4,150 feet. The formation contains marine fossils at many horizons, the highest being within 140 feet from the top. It is difficult to determine a positive plane of separation between Pierre and Fox Hills in this region so that authors frequently employ "Montana" or

<sup>81</sup> A. L. Beekly, *Bull.* 596, 1915, pp. 20, 43, 45.

<sup>82</sup> N. H. Darton, *Bull. Geol. Soc. Amer.*, Vol. 19, 1908, 459, 460.

"Pierre-Fox Hills" to designate the whole mass. Just above the one persistent sandstone, Pine Ridge of Siebenthal, is a coal bed and others, unimportant, are in the succeeding 560 feet of black shale; but in the overlying beds no coal was found. It may be that the upper part of the section, including the Pine Ridge sandstone, is equivalent to Mesaverde, Lewis and Fox Hills, the coal being in the Mesaverde.

Farther west in Fremont County, north from Sweetwater, the lower shales are 2,250 to 3,000 feet, increasing eastwardly, while the upper division, of which erosion has spared 550 feet, has at base a sandstone, 200 to 250 feet thick. Overlying this is a bed of carbonaceous shale, which occasionally contains a seam of coal. Here the Mesaverde conditions are distinct for the overlying mass consists of "sandstones, with intercalated gray shales, sandy shales and coal beds." The lowest coal is 8 feet thick at 10 miles east from Lander.

The Pierre is without coal<sup>83</sup> in the Black Hills and is wholly shale. The Sussex field at 100 miles southwest from the Black Hills has, according to Wegemann, 4,650 feet of Montana rocks, of which he refers the upper 700 feet to the Fox Hills. The Pierre has a sandstone, 175 feet thick, at about 1,000 feet from the base and, at 2,300 feet, another sandstone, the Parkman of Darton's Bighorn section, 350 feet. This sandstone contains masses of petrified wood with shells of turtles and bones of *Trachodon*. In the shaly portions near the base, it has thin seams of low-grade bituminous coal, high in ash. Thin seams are associated in the southern part of the field with another sandstone, about 300 feet above the Parkman. The Pierre rocks are predominatingly shale. The fauna of the Parkman sandstone, according to T. W. Stanton, is similar to that of the Mesaverde in Colorado and of the Claggett in Montana.

The Bighorn Basin of north central Wyoming lies west from the Bighorn Mountains, occupying parts of several counties and extending into Montana. It was examined by Washburne and Woodruff and in part by Darton.<sup>84</sup> The indefinite relations of the upper

<sup>83</sup> N. H. Darton, Folios 127, 128, 1905.

<sup>84</sup> N. H. Darton, Prof. Paper 51, 1906, pp. 13, 58, 59; E. G. Woodruff, Bull. 341, pp. 204, 208-210, 215; Bull. 381, pp. 173-175, 178; C. W. Washburne, Bull. 341, pp. 168, 172-179, 187, 195.

part of the column near Bighorn Mountains are shown by the fact that Darton embraces the whole above his Parkman sandstone in a single formation, the Piney. Woodruff in the southeastern part of the basin found indefiniteness throughout, but the succession is suggestive of the section as recognized in Montana and northward, there being at base shales with Pierre fossils succeeded by two sandstone and shale members which he referred provisionally to the Eagle sandstone and Claggett shale of Montana, while he terms the higher beds merely Undifferentiated Montana. All become more shaly toward the east. Coal seams were seen in the upper division, but they are lenticular and unimportant: the quantity decreases toward the north. In the western portion, Woodruff recognized the Eagle sandstone of the Montana section, but none of the higher divisions could be identified. Coal seams in the Eagle are lenticular, but occasionally they are important. One near Gebo is 11 feet thick; in Grass Valley, a seam, 7 to 8 feet, is mined, but within a fourth of a mile toward the west it is too thin to be worked, while, at an equal distance toward the south, it becomes much thinner and so broken by partings as to be worthless. Similar variations in the Eagle coals were observed elsewhere within this portion of the field. Farther south in the Buffalo Basin no coal has been found in the Eagle. The Undifferentiated Montana has some coal seams but they are wholly unimportant.

In the northeastern part of the basin, extending into Montana, Washburne was able to recognize all members of the Pierre as they had been determined in Montana—Bearpaw shale, Judith River Formation, Claggett shale, Eagle River sandstone, the last resting on Colorado shale. The Bearpaw, evidently the Lewis of localities farther south, is marine, 150 feet thick and without coal; the Judith River variegated clays and sandstone, 300 to 400 feet, has abundance of leaves and bones but seems to be without coal; the Claggett, 400 to 500 feet, consists of massive gray to yellow sandstone with interbedded shales and has marine fossils in many portions; the Eagle, 150 to 225 feet, has two or three massive sandstones. The upper part of the Colorado shale, for 1,000 feet, is without fossils, but it differs lithologically from the shales below and it may be taken as, at least in part, representing the lower shales of the Pierre as in the

southern portion of the Bighorn Basin. Coal is present in the Claggett and the Eagle. The Claggett seams are very thin, nowhere exceeding 21 inches, and in all cases the coal is so dirty as to be worthless. The Eagle seams are of capricious distribution. There are workable beds in the southeastern corner of the basin, but they disappear northwardly before Bighorn County is reached and are replaced with yellow sandy shales. Black shales appear north from the city of Basin and these near Garland contain very thin seams of coal. Elsewhere in that neighborhood, these coal horizons are marked only by black shale with coaly streaks. An anticline near Silvertop, close to the Wyoming-Montana line, brings up the Eagle. There is but one workable seam in that formation on the Wyoming side, but there are two beyond the line in Montana. The Bridger coal field is west from the anticline and extends along the Chicago, Burlington and Quincy railroad to beyond Bridger in Montana. Some important coal deposits are in the Montana portion, but none in Wyoming, and all trace of coal disappears at a short distance west from the railroad. The Eagle coals are all well-jointed and show no woody structure. They illustrate well the irregularity of coal deposits in an extended area.

The eastern part of Montana is a rolling plain, the mountains of Wyoming, Colorado and New Mexico having become insignificant, as the disturbed area is confined to the western border; but mountain-making was energetic there, west from the 109th meridian, and the whole section of Cretaceous is shown at many localities. In this disturbed area, one is west from the Bighorn Basin, as well as the western boundary of Colorado and New Mexico, so that conditions should bear resemblance to those observed in Arizona, Utah and western Wyoming.

The most southerly coal field is that near Electric, in Park County, about 100 miles west from Bridger. There as well as in some petty areas at the north, Calvert<sup>85</sup> was unable to recognize the subdivisions of the Pierre and grouped the section, about 1,000 feet, as Montana. The upper portion, about 330 feet, consists of sandstone and shales with some carbonaceous shale but no coal; the middle portion, about 230 feet, is largely sandstone and sandy shale

<sup>85</sup> W. R. Calvert, Bull. 471-E, 1912, pp. 28-66.

with several beds of dark shale and some seams of coal; the lower portion, about 370 feet, and without coal, is sandstone except 78 feet of sandy shale at the top. Four coal seams were seen in one section, three of them thick enough to be mined; but the coal is very dirty; that from the best contains 20 to 24 per cent. of ash and the washed coal, utilized in making coke, retains 21.71 per cent. This Montana of Calvert rests on a mass of shale and sandstone containing Colorado fossils throughout; which makes probable that basal member of the section may be equivalent to the shales of the Lower Pierre and that the coal-bearing member may be at the Eagle or Mesavèrde horizon, there being Mesaverde fossils throughout. The "Montana" beds underlie conformably the Livingston formation, a mass of andesitic material. Calvert found similar conditions in the Livingston coal field farther north in the same county, except that his Montana beds are thinner. There are not less than 3 seams of coal, 2 to 20 feet thick; but they vary rather abruptly in thickness and the coal is of uncertain quality. Two samples from one mine gave 8.77 and 17.5 per cent. of ash; analyses of samples from other mines yielded 8.44, 10.92, 10.99, 14.9, 27.53 and 31.51 per cent. in air-dried coal. Cross-bedded sandstones were noted by Calvert in both fields.

Newberry<sup>86</sup> noticed that coal near Bozeman, in the Livingston field, contains a large quantity of yellow, translucent, almost amber-like resin. Weed<sup>87</sup> examined the same fields at an earlier date and called especial attention to the uneven floor of the coal seams. This as well as the occasional disappearance of the coal led him to believe that the coal seams had been formed in depressions of the surface. He found *Unio* in beds associated with the coal seams of the Electric coal field.

In Meagher County, north from Park, Stone recognized the four formations. The Bearpaw shale, marine throughout, has no coal; the Judith River, brackish and fresh water, has some lenses of coal, usually very thin and of short lateral extent; when of workable thickness, their coal is apt to be dirty. The Claggett, marine and brackish, appears to be without coal. The Eagle has coal, but

<sup>86</sup> J. S. Newberry, *Ann. N. Y. Acad. Sci.*, Vol. 3, 1884, p. 245.

<sup>87</sup> W. H. Weed, *Bull. Geol. Soc. Amer.*, Vol. 2, 1891, pp. 349-364.

it is uncertain both as to quantity and quality; when a seam becomes thick it has much foreign matter and is in great part worthless. Stone could not determine whether or not the Eagle coals are lenses; but the quality is inferior with from 17 to 37 per cent. of ash. Here, as in districts farther south, the rocks are mostly sandstone and sandy shale.

The Lewistown coal field in Fergus County is about 60 miles north-northeast from the Meagher area and its western limit is near the 110th meridian. Calvert<sup>88</sup> found no rocks newer than the Claggett, which like the underlying Eagle, consists of sandstone and sandy shale; cross-bedded sandstones are characteristic. The only coal seam is in the Eagle, at 10 feet from the base. It is merely a coaly layer. Bowen<sup>89</sup> examined the Cleveland field, about 80 miles east of north, and the Big Sandy field at an equal distance west of north from Lewistown. In both fields the Judith River and the Eagle are characterized by irregularity of the deposits and the sandstones are often cross-bedded, occasionally ripple-marked. The Eagle becomes shaly in the eastern field. Thin seams of impure coal were seen in the Judith River within both fields; the Eagle has similar streaks in the southern part of Big Sandy but no coal was seen in the northern part of that field nor in the Cleveland field. The Eagle coal is usually bony.

The Milk River coal field is north from the Cleveland and extends to the Saskatchewan line. Pepperberg<sup>90</sup> states that the Judith River coals, all near top of the formation, are lenses, which become thinner and poorer toward the east. The variation in thickness is abrupt; a lens, 9 feet thick, decreased to a fraction of an inch within a short distance along the outcrop. The quantity of bone is a serious drawback in many mines, so that the product is inferior, because of high ash. The coal is subbituminous and contains mineral charcoal as well as resins. All deposits in the Judith River are lenticular and the sandstones are locally cross-bedded. Some streaks of coal were seen in the upper part of the Eagle, but they are insignificant. The sandstones of both formations have become much less prominent.

<sup>88</sup> W. R. Calvert, Bull. 341, p. 110; Bull. 390, pp. 32, 34.

<sup>89</sup> C. F. Bowen, Bull. 541-H, 1914, pp. 45-47, 60-65, 77-80.

<sup>90</sup> L. J. Pepperberg, Bull. 381, pp. 85, 86, 94.

Teton County is very near the western boundary of Cretaceous deposition in Montana. It reaches the border of Alberta and the coal-bearing area is between meridians  $112^{\circ} 30'$  and  $113^{\circ}$ . Stebinger's<sup>91</sup> report on this area and his general discussion of the Montana Cretaceous have done much to solve serious problems in correlation. The succession in the Teton coal field is St. Mary River formation, correlated with the Laramie; Horsethief sandstone, 225 to 275 feet, which Stebinger has shown to be same as the Lennep sandstone and the Fox Hills; Bearpaw shale, with characteristic features of the formation, 490 feet; Two-Medicine formation, 1,950 feet, gray to greenish gray and whitish clay shales, with some sandstones, which are important in the basal 250 feet; Judith River leaves, mollusks and bones of reptiles are present; it is apparently continental in origin, there being evidence of only one marine invasion, and that is at about 200 feet from the base. The formation includes Judith River, Claggett and the upper or coal-bearing portion of the Eagle. The marine deposit near the base contains the Claggett-Fox Hills fauna, indicating deposition in a retreating sea. Within the disturbed region on the western side of the county, one finds it difficult to distinguish this formation from the St. Mary; the conditions during deposition must have been very similar in both. Virgelle sandstone, 220 feet, the basal sandstone of the Eagle, is gray to buff, coarse, cross-bedded sandstone, becoming slabby to shaly in the lower half.

Two-Medicine and Virgelle, traced northward into Alberta, prove to be the Belly River formation, described by G. M. Dawson. The Two-Medicine is characterized by extreme irregularity of the beds; sections only a few hundred feet apart are wholly dissimilar. Fossil wood is distributed throughout the formation, knots and entire sections of compressed trunks of trees are of common occurrence. The continental deposits, except the Fox Hills, become thinner toward the east, so that in the Black Hills of northeastern Wyoming the Pierre is represented only by marine shales.

No coal aside from petty lenses was seen in the Virgelle; the Two-Medicine has three coal zones, one at the base, another at 250

<sup>91</sup> E. Stebinger, Bull. 621-K, 1916, pp. 126, 127, 131, 140, 144; Prof. Paper 90-G, 1914, pp. 61-68.

feet higher and a third at the top, but coaly material is present in other portions as carbonaceous shale. The highest coal is found in the northern part of the county, but it disappears south from Valier, about 50 miles from the International Boundary and no trace of it has been found farther south in a distance of not less than 50 miles. It is thin in Teton County but increases toward the north beyond the boundary and is 6 feet thick at Lethbridge, where the coal is good. The seams of the middle zone are thin and yield only impure coal, while the lower zone has two seams which are persistent in the Valier district on the easterly side of the county. The upper one is 2 feet 6 inches, with 2 feet of coal, while the lower one, with extreme thickness of 5 feet 8 inches, contains only 8 inches of clean coal. These seams vary much in thickness, but the upper one is mined. Samples of clean coal gave 14.07, 13.9, 14.5 and 28.6 per cent. of ash.

Dowling,<sup>92</sup> in his synopsis of conditions in the western states of Canada, says that the depressions, in which Mesozoic rocks were deposited, appeared in the Rocky Mountain area, where Triassic and Jurassic beds are found. The Jurassic sea invaded a narrow depression, now elevated as the Rocky Mountains and the Foothills. Land conditions prevailed during part of the Lower Cretaceous, but occasional submergences extended to a short distance toward the east, whereas in the United States they extended as far east as the Black Hills of Wyoming. More general submergence eastwardly came in the Upper Cretaceous, while on the western side there is evidence of shallowing during the earlier periods. Marked proof of shallowing on that side is evident during the Montana, for land conditions are shown by the coal seams and by the type of sediments, but marine conditions prevailed at the east. Submergence followed and the sands at the west were covered with marine shale. The closing part of Cretaceous time was characterized by emergence, with brief periods of submergence, as shown by land and shallow water conditions, giving an abundant flora and a brackish-water fauna: this closing stage is the Edmonton-St. Mary formation. The vast accumulations unsettled the equilibrium of the area whence they had been derived and, toward the close of the

<sup>92</sup> D. B. Dowling, Geol. Survey of Canada, Mem. 53, 1914, pp. 32, 33.

Eocene, crustal movements followed, which formed the Rocky Mountains. But the energy was expended in a narrow area so that at the east, even in the Foothills, one finds nothing exposed below the Middle Cretaceous.

The conditions noted by Dowling are very distinct in southern Alberta. McEvoy, in the mountain portion of the Crowsnest coal field, found the Upper Cretaceous merely a mass of sandstone and conglomerate, 7,000 to 8,000 feet thick and without coal. In another part of the Rocky Mountain area, near the International Boundary, McConnell saw no coal in the upper part of the section, which contains great beds of conglomerate, some of them 150 feet thick. It seems to be impossible to differentiate the formations in this area; but McLearn, at a short distance eastward in the Foothills, recognized the Bearpaw and the Belly River, the latter being the equivalent of Judith River, Claggett and Eagle.<sup>93</sup> The sea-invasion during Claggett did not reach much of southern Alberta and did not extend so far westward as did that during the Bearpaw. No coal was seen in the basal sandstone of the Belly River formation, but 4 thin seams were seen in the overlying 50 feet of clay and shale. The higher deposits are sandstones and shales, alternations of "sand bottoms and clay bottoms" with *Unio* and gastropods in the sands and gastropods in the clays. The faunules are fresh-water. Mackenzie<sup>94</sup> saw no coal in the Allison (Belly River) formation on Oldman River, where it is 2,000 feet thick and consists chiefly of sandstones, massive to shaly and often cross-bedded.

Dawson<sup>95</sup> examined an extensive area within southeastern Alberta, mainly along the Bow and Belly Rivers, but reaching into the Milk River region near the International Boundary. He offered tentative names for the formations. The Pierre shales, 750 feet thick, contain intercalated beds of sandstone, which increase toward the mountains. A coal zone was seen at the top on Bow River and another at the base on Belly River; the latter was seen also at several

<sup>93</sup> J. McEvoy, Ann. Reps. Geol. Survey Canada, Vol. XIII., 1900, Part A, pp. 84-88; R. G. McConnell, the same, 1886, Part D, pp. 16, 17; F. H. McLearn, Summary Report, 1914, pp. 62, 63.

<sup>94</sup> J. D. Mackenzie, Summary Report for 1912, pp. 235-246.

<sup>95</sup> G. M. Dawson, Geol. Survey of Canada, Reps. Prog. for 1882-83-84, Part C, pp. 36, 52, 62, 69, 71.

places on St. Mary River. At the mouth of the latter river, in a section by R. G. McConnell the lower zone has 3 coal seams in a vertical distance of 132 feet, the thickest being from 3 feet to 3 feet 6 inches. This zone is persistent and its coal is mined on Belly River. The Belly River formation has few thick coal seams; its sandstones are gray to yellow, hard and the surfaces often show ripple marks and worm trails. In one case, the ripples indicate movement toward S. 36° W. The "Lower Dark Shales" of Dawson were seen on Rocky Ridge in the Milk River region. Dowling<sup>96</sup> has shown that the Pierre shale is the Bearpaw, the Belly River of southeastern Alberta is the Judith River and the lower dark shales of Rocky Ridge are the Claggett. Evidently he places the coal of Dawson's Pierre in the upper or fresh-water part of the Belly River. The area within Alberta, in which the Belly River with its important coal seams is exposed, is not less than 24,000 square miles; its presence has been proved by borings in a great area, where it is deeply buried under later formations. In a report on the Sheep River Oil and Gas field, Dowling has emphasized the increasing thickness of Bearpaw toward the east; in the Foothills, it is 650 feet, on Red Deer River, east from Calgary, 750, on the Cypress Hills, 900 and on Sheep River, about 1,200 feet.

The coal seams of the Pierre formations become unimportant north from the latitude of Edmonton. They are few and thin, sometimes wholly wanting, as appears from observations by G. M. Dawson,<sup>97</sup> Dowling, Tyrrell and McConnell. Dawson found no seam thicker than 6 inches on Pine River. The associated rocks are sandstone and sandy shale, the former cross-bedded and ripple-marked. On Smoky River he saw a soft massive sandstone, with abundant fragments of plants, which in one place are "distinctly representing the base and roots of a tree, and evidencing a terrestrial surface. Overlying this is a thin carbonaceous film which, at a short distance up the river, becomes a seam of lignitic coal, two and a half inches in thickness." The Dunvegan sandstone of Peace River, regarded as the Belly River formation, has no coal.<sup>98</sup> It disappears toward the east and is not present on Athabasca River.

<sup>96</sup> D. B. Dowling, *Mem.* 53, 1914, pp. 28-31, 51, 53.

<sup>97</sup> G. M. Dawson, *Rep. for 1879-80, Part B*, pp. 117, 118.

<sup>98</sup> R. G. McConnell, *Reps.*, Vol. VI-D, 1893, p. 53.

*The Colorado Group.*

The Niobrara and Benton are sufficiently distinct in the region of the Front Ranges and eastward as far north as Wyoming. The Niobrara consists of black shales and limestones weathering to chalky whiteness; while Benton is mostly shale, but with bands of sandstone and more or less persistent limestones. Farther west, however, the deposits answering to the Niobrara-Benton time interval lose the limestones and the mass becomes practically continuous as shale, though varying much at different horizons. The term Colorado Shales finds application in those areas, where Niobrara cannot be recognized and where Benton conditions, as shown at some places by the continuing fauna, remained comparatively unchanged. The term Mancos was introduced in southwestern Colorado, to designate the shale mass between the Mesaverde (Middle Pierre) and the Dakota. It is a lithological term for use in the field and includes Lower Pierre as well as Niobrara and Benton.

The Colorado interval is represented by marine deposits in by far the greater part of the Cretaceous area, but in New Mexico the isolated coal fields give abundant evidence that the mainland was not far distant, as coarse deposits make their appearance, while farther west in the same state as well as in Arizona and Utah one finds conditions such as characterized the Middle Pierre, marking the strife between land and sea, sandstones and coal beds being the especial features.

The relations of deposits in the southernmost fields of New Mexico are somewhat obscure, the areas being very small and isolated. But there is little room for doubt farther north in the Cerillos and other fields southeast from the San Juan Basin. Lee<sup>99</sup> obtained a detailed section of the Mancos in the Cerillos field. The upper portion is distinctly Pierre and the lower portion, about 2,200 feet, is certainly Colorado in the lower 1,200 feet. One finds here the several subdivisions of the Benton, as recognized east from the Front Ranges, but the limestones of the Niobrara interval have disappeared. A sandstone, Tres Hermanos of Herrick and Johnson,<sup>100</sup>

<sup>99</sup> W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, pp. 623, 631, 658, 651-654.

<sup>100</sup> C. L. Herrick and D. W. Johnson, *Bull. Univ. New Mex.*, Vol. II, p. 13.

20 feet thick and about 82 feet from the base, is hard, quartzose, cross-bedded and in thin irregular layers, which have rippled surfaces with worm borings and indefinite markings. Of especial interest are impressions very similar to *Halymenites major*, associated with an offshore fauna. At the base of the Benton are conglomerate, 5 feet and carbonaceous shale, 5 feet, with a few inches of coal at the top.

The Tres Hermanos sandstone is 90 feet above the base and only 5 feet thick in the Hagan field, west from Cerillos; though so much thinner, it has the same features. The thin coal bed and its overlying conglomerate, seen in Cerillos, appear to be wanting. A Benton fauna is present in the lower 670 feet of the section. Conditions are practically the same in the Tijeras field. In the Puerco field no coal was seen at base of the Benton, but a conglomerate, 5 feet thick, with pebbles of quartz and chert, recalls that overlying the coal in Cerillos.

In the southwest corner of the San Juan Basin, as Gilbert<sup>101</sup> has shown, the Colorado is represented by mostly sandstones for 180 feet at the base, containing 3 coal seams about midway, while above are 380 feet of carbonaceous and clay shale underlying sandstones and sandy shales. The whole thickness is not far from 850 feet. The coals are not persistent and they were seen in only one section. Elsewhere they are replaced with carbonaceous shale. Winchester<sup>102</sup> says that in the Zuni Mountain region, a few miles south from the locality of Gilbert's section, the Mancos is 60 per cent. sandstone. This sandstone decreases northwardly as do also the coal seams, which disappear in the northern part of the area examined by him.

The Mancos shale is thin in the main portion of the San Juan Basin, the whole thickness, according to Gardner,<sup>103</sup> being not more than 800 feet. Coal seams occur in the upper 500 feet, where the rocks are sandy; there are no coals in the lower part, where clayey beds prevail. The coal seams are usually thin, though occasionally reaching 3 feet, are double or triple and often contain much bone. One seam at times becomes workable, with 3 to 5 feet of sub-

<sup>101</sup> G. K. Gilbert, U. S. Geog. Explorations, etc., Vol. III., 1875, pp. 550, 551.

<sup>102</sup> D. E. Winchester, *Journ. Wash. Acad. Sci.*, Vol. IV., 1914, p. 300.

<sup>103</sup> J. H. Gardner, Bull. 341, pp. 366, 369, 373, 375; Bull. No. 381, p. 462.

bituminous coal which contains much resin. Eastwardly along this southern border no workable seams occur, while farther north along the eastern outcrop only traces of coal were seen. The sandstone decreases in that direction. Lee appears to have found no coal in the Colorado beds along the northeastern border of the basin, but he was able to recognize the Tres Hermanos sandstone.

In Arizona the near approach to the source of sediments is manifest. The most southerly fragment of Cretaceous is the Deer Creek coal field,<sup>104</sup> about 150 miles southwest from the southern termination of the San Juan Basin, near the junction of the Gila and San Pedro Rivers. In the lower or southern part of the field, according to Campbell, 400 to 500 feet of coarse greenish gray sandstone with some shale rest on the Carboniferous limestone. The fossils are imperfect and suffice only to prove Cretaceous age. Three coal seams, much broken and thin, were found in a shaft within the basal 60 feet. The coal is poor; the best has 34.78 per cent. of ash. The Pinedale coal field is about 100 miles north from the Deer Creek area. There Veatch<sup>105</sup> found about 500 feet of deposits containing Benton fossils as determined by T. W. Stanton. The two coal seams are near the base, 10 to 15 feet apart, and are only 25 feet above rocks of Pennsylvanian or Permian age. The seams are 12 and 3 feet thick, but coal from the upper one is very bad, having 54 per cent. of ash. The lower one has some good coal with only 10 per cent. A much more extensive field is that of the Black Mesa<sup>106</sup> in the northeastern corner of the state. The Cretaceous is about 700 feet thick and coal seams were found near the base as well as above the middle. The lower group is within the basal 55 feet and its seams are 7 and 15 feet thick. The upper bed yields a fairly good coal, bituminous and with about 14 per cent. of ash. The lower seam is a worthless mass of shale and coal. The higher beds show numerous seams 2 to 12 feet thick; the coal is evidently inferior, but in default of better material it is used as fuel.

Benton deposits are present in isolated areas within Utah as far west as the 113th meridian along the Arizona border. Almost 45

<sup>104</sup> M. R. Campbell, Bull. 225, 1904, pp. 241-258.

<sup>105</sup> A. C. Veatch, Bull. 431, 1911, pp. 239-241.

<sup>106</sup> M. R. Campbell and H. E. Gregory, Bull. 431, pp. 229-238.

years ago, Gilbert discovered in Washington County a mass of shale about 635 feet thick, including at base a coal group, somewhat more than 130 feet thick, with 5 seams, 4 inches to 4 feet thick. Howell, in Park County, next east, found two coal groups, separated by 500 feet of barren measures, containing Benton fossils. The lower coal group is capped by an oyster bed 1 to 5 feet thick. Thirty-five years later, Richardson examined some small fields in Washington, Kane and Iron Counties.<sup>107</sup> The coal seams are from 50 to 500 feet above the assumed base of the Cretaceous and they are lenses. Ordinarily only one workable bed appears in a section but in some cases there are as many as six. In the Harmony field, only 600 feet of Cretaceous remain, containing 6 seams of coal and shale, 7, 11, 6, 11, 17 and 6 feet respectively, with 4, 5, 4, 7 and 4 feet of coal. At best this coal is very poor, two air-dried samples having 22.89 and 33.96 per cent. of ash. The seams are similarly lenticular in the Colob field. In this field on the North Fork of Virgin River, Richardson saw, at about 100 feet above the basal conglomerate, a coal seam with this structure: carbonaceous shale with fossils; bituminous coal, 2 feet 5 inches; cannel, 5 feet 6 inches. This seam disappeared quickly toward the north, east and southeast; but a similar seam was found at 10 or 12 miles toward the southeast. The cannel at these localities is brownish black with dull greasy luster. The volatile is very high and the hydrogen in dried coal is practically twice as much as that in the ordinary coals. D. White examined it under the microscope and ascertained that its structure and composition are essentially those of high-grade cannel. The Colob coals are better than those of the Harmony field and have from 10 to 15 per cent. of ash. They vary from low grade bituminous to subbituminous. In many cases a coal seam overlies or underlies fossiliferous limestone.

Lee examined a small field in Iron County, north from Washington, where he measured a section of 1,200 feet in which sandstone predominates. The coal seams are in a group of shales and thin limestones, about 150 feet thick, beginning at nearly 800 feet from the basal conglomerate. The fossils are of Benton age. One coal

<sup>107</sup> G. K. Gilbert, U. S. Geog. Explor., etc., Vol. III., pp. 158, 159; E. E. Howell, the same, p. 271; G. B. Richardson, Bull. 341, pp. 379-400.

bed is divided by bands of limestone containing brackish-water mollusks. Another has marine limestone roof and floor, with marine fossils, but one of its partings has *Physa*, *Planorbis* and other fresh-water forms, related to those of ponds and streams. Several of the sandstones are cross-bedded.<sup>108</sup>

Lupton examined the Emory coal field in the southern part of Castle Valley, about 40 miles northwest from the Henry Mountains, which had been studied by Gilbert.<sup>109</sup> At approximately 600 feet from the base is the Ferron sandstone, regarded by Lupton as equivalent to Gilbert's Blue Gate sandstone. It is 800 feet thick at the southwest but becomes thinner toward the northeast until at north end of the valley it is but 75 feet. This sandstone holds all the Benton coal seams, but these are confined to the southern part of the valley, disappearing toward the north as the sandstone decreases in thickness. Local unconformities which one must accept as evidence of contemporaneous erosion, occur within this sandstone. The coal-bearing area is a narrow strip about 33 miles long. Fourteen coal horizons were recognized but the deposits are lenticular and correlations are uncertain. The variations are abrupt; in one case, from one to 20 feet within a very short distance. Many of the seams are injured seriously by partings. The coal is low grade bituminous of very fair quality, with color and streak black, and contains resin. In portions it is thinly laminated, but at times the dull layers are several inches thick and resemble cannel.

The most easterly locality in the southern part of the Uinta Basin,<sup>110</sup> at which the Benton coals have been recognized, seems to be that on the Gunnison River about 60 miles east from the Utah-Colorado line. There Lee found at base of the Benton a succession of sandstone and shale with maximum thickness of about 80 feet. The lenses of coal, a few inches to 3 feet thick, occur in the shales. Near the junction of Gunnison and Grand Rivers, 5 deposits of coal, one to 3 feet thick, were seen, but these lenses are too indefinite in extent and contain too much carbonaceous shale to justify mining. The ash in air-dried coal varies from 6 to 34.5 per cent. The sand-

<sup>108</sup> W. T. Lee, Bull. 316, 1907, citations from pp. 361-373.

<sup>109</sup> G. K. Gilbert, "Geology of the Henry Mountains," 1877, pp. 4-10;  
C. T. Lupton, Bull. 628, pp. 30, 31, 47-74, 78.

<sup>110</sup> W. T. Lee, Bull. 510, 1912, pp. 24, 25, 68.

stones are more or less flinty, are cross-bedded, ripple-marked and locally conglomerate. These coals have been placed in the Dakota by several students, but the presence of fossils confirms Lee's reference to the Benton. The Ferron sandstone cannot be recognized in this part of the basin and the coals of Castle Valley are wanting.

No observer has noted the existence of Benton coals on the northern side of the Uinta Basin within Colorado, but they have been recognized in two outlying fields along the northwestern border in Utah, which have been described by Lupton.<sup>111</sup> The western or Blacktail Mountain coal field is almost due north from the Emery field. The Mancos formation is about 2,650 feet thick. The upper part, 1,450, consists of shale; the middle, about 250 feet, is chiefly sandstone and has coal seams; the lower part is sandstone and shale. The shales increase and the sandstone decreases toward the east; the upper shale is but 800 feet thick in the western part of this field. Four coal seams were seen, 3 to 11 feet thick, but extremely variable. The coal is very similar to that from the Mesaverde, though 3,500 feet lower in the column; some of it is very good, with but 3 per cent. of ash and 10 per cent. of water in the air-dried coal. In the Vernal coal field, 30 miles farther east, the Mancos is not far from 2,500 feet thick, but the upper or shale division is 2,100 feet and the lower or sandy division is about 400 feet, with some coals near the top. It is quite possible, as suggested by Lee, that these coals are at same horizon with those of the Ferron sandstone. They are irregular but in some cases yield a good coal.

The Coalville coal field, about 30 miles northeast from Salt Lake City, Utah, was examined by Wegemann.<sup>112</sup> There, at somewhat more than 1,600 feet from the base of the Cretaceous section at Coalville, is the important coal seam known as the Wasatch. The roof is sandstone, locally conglomeratic, with sometimes a thin shale intervening. It appears to be quite regular. The floor is shale or sandstone and is irregular, there being "rolls" which occasionally cut out as much as 5 feet of the coal. The coal seam is from 5 to 14 feet thick but as a rule, the variations are not abrupt. The coal as mined at Coalville is of excellent quality. It is stated

<sup>111</sup> C. T. Lupton, *Bull.* 471-*I*, 1912, pp. 13, 35, 44.

<sup>112</sup> C. H. Wegemann, *Bull.* 581-*E*, 1915, pp. 161-184.

that work was abandoned in one mine because the bed thinned abruptly, the coal being cut out by a "sand roll" or deposit of coarse sand and gravel in the roof of the bed. At about 850 feet below the Wasatch seam, thin coals were seen, which are known as the Spring Canyon beds. The coal is impure and worthless; it is possible that these belong at a Bear River horizon.

The Coalville field is an outlier of the Green River Basin, which is reached in Uinta County of Wyoming near the 111th meridian or nearly 100 miles west from the Utah-Colorado line and probably 25 miles east from the meridian passing through Emory in Castle Valley field of Utah. The relations of the lower part of the section were a source of much perplexity, as the fresh-water fauna had led to the belief that it belonged to the Laramie or possibly even to the Tertiary. Its place in the column was determined by Stanton<sup>113</sup> who showed that it intervened between coarse sandstones and conglomerates below and well-defined Colorado above. Knight<sup>114</sup> recognized an important coal-bearing formation in the southern part of the county, which he named the Frontier. It consists of thick sandstones with coal beds and it may be practically equivalent to the deposits containing the Wasatch seam at Coalville. At a later date Veatch reported upon the southern and Schultz<sup>115</sup> upon the northern part of the county. The thickness of deposits in this area is enormous; Veatch assigns not less than 2,000 feet to the Niobrara, 4,200 to the Benton and 0 to 2,400 to the Bear River. The Frontier sandstone formation, the upper part of the Benton, is about 2,400 feet thick, consists of alternating sandstones and clays, with numerous coal seams. The important coals are the Kemmerer group near the top, consisting of 3 seams within a vertical distance of 90 feet; the highest bed has an extreme thickness of 5 feet, the main Kemmerer is from 5 to 20 feet thick in the mines, but along the outcrop, the variability is much greater, for at some localities between the mines it is very thin, at times absent. At 550 feet below the main Kemmerer is the Wilson bed which is not

<sup>113</sup> T. W. Stanton, "The Stratigraphic Position of the Bear River Formation," *Amer. Journ. Sci.*, Vol. XLIII., 1892, pp. 98-115.

<sup>114</sup> W. C. Knight, "Coalfields of Southern Uinta County, Utah," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 542-544.

<sup>115</sup> A. C. Veatch, *Bull.* 285, pp. 333, 337, 340; A. R. Schultz, *Bull.* 316, p. 215.

present in the southern part of the field, but is 5 feet 8 inches at Kemmerer, where it yields a coking coal. The Carter bed is 1,300 feet below the Kemmerer and the Spring Valley, 1,475. The last, 5 to 6 feet thick, is apt to be dirty.

The Bear River coals are occasionally thick, as much as 6 feet, but the coal is so dirty as to be worthless. This formation, 2,400 feet on the western side of the county, is only 100 feet at the east side. The Frontier coals are bituminous, of high grade, with low ash and water content; the Coalville coal is subbituminous.

The Frontier sandstone does not outcrop in the Rock Springs field; in northern Carbon County Smith saw it with all the lithological features observed in Uinta County, but without coal. It is 900 feet thick in the southern part but only 500 in the northern part of his district; showing a great decrease toward the east. The Bear River is only 30 feet thick, but this has some thin and worthless streaks of coal. Veatch<sup>116</sup> in the eastern part of the same county found 400 to 800 feet of Frontier, but no coal, while the coaly streaks in shales overlying the Dakota are thin and worthless. Woodruff saw thin streaks of coal, 6 to 8 inches, below the middle of the Colorado, in Park County of Wyoming, almost due north from the Rock Springs coal field. No observer has reported the occurrence of coal at the Frontier horizons at any locality in Montana or in Alberta or anywhere east from the 109th meridian in Wyoming or the 108th in Colorado, but the lowest coal horizon, that resting on the Dakota, reaches to the 105th in Carbon County of Wyoming and, in northern New Mexico, along the southern border, it is present occasionally to near the same meridian. In New Mexico it extends northwardly for only a short distance.

### *The Dakota.*

The Dakota or basal member of the Upper Cretaceous is a sandstone, more or less massive and locally conglomerate in the eastern or Rocky Mountain region. It is often cross-bedded and sometimes ripple-marked. At some localities farther west it contains much conglomerate. The thickness rarely exceeds 200 feet. Land

<sup>116</sup> E. E. Smith, Bull. 341, p. 226; A. C. Veatch, Bull. 316, p. 247; E. G. Woodruff, Bull. 341, p. 203.

conditions existed at few localities and in by far the greatest part of the region no coal occurs. The thin lenses, referred by some writers to this formation, belong rather to the Benton.

### *The Kootenai.*

The Dakota, as described by the earlier students in the Front Range region of Colorado and New Mexico, consists of two sandstones separated by shale of variable thickness. Darton's collections in the Black Hills of northeastern Wyoming proved that the Dakota of that region is complex, that only the upper sandstone is Upper Cretaceous, the other deposits belonging to the Lower Cretaceous. He was convinced that a new name was necessary and offered Cloverly formation as substitute for Dakota. At a somewhat later time Darton, Lee and Stanton discovered somewhat similar conditions in Colorado and New Mexico. In Montana, this formation proved to be practically equivalent to the Kootenai formation of G. M. Dawson, which is important in the Rocky Mountains region within Alberta and British Columbia. This earlier name has been accepted throughout; but in some localities it appears to include the upper sandstone or Dakota. The Kootenai has not been recognized in Colorado and New Mexico west from the Front Ranges except in the Park area of Colorado, where it was seen by Beekly. Elsewhere the "Dakota" sandstone rests on a mass of clays containing some sandstones, the Morrison formation, of which the relations are not wholly clear, though in recent years the paleontologists have shown increasing inclination to regard it as Lower Cretaceous. It has no coal.

The Kootenai is recorded as coal bearing nowhere south from the Black Hills, where Darton gives the succession, as Dakota sandstone, 10 to 100 feet; Fuson shale, 10 to 100 feet; Lakota sandstone, 25 to 300 feet; forming the Cloverly formation of his earlier publications.<sup>117</sup> The Lakota, mainly sandstone, contains the coal. The sandstones are mostly hard, massive, coarse and cross-bedded; but in many places they are slabby, ripple-marked and locally they are conglomeratic. Lenses of coal occur near the base and at times

<sup>117</sup> N. H. Darton, Folios 127, 128, 1905; Prof. Paper 51, 1906, pp. 50-53; Bull. 260, 1904, pp. 429-433; Prof. Paper 65, 1909, pp. 12, 40-48.

attain commercial importance. Two are near Aladdin, one of them, 2 feet to 3 feet 6 inches, the other, 10 feet above, being thinner. The extreme thickness is at a little way north from Aladdin where the lower lens becomes 8 to 9 feet; but both thin away, being replaced with impure coal, before disappearance. The coal at Aladdin is soft and bituminous, as it is also at Sundance. In the Cambria district, on southwest side of the region, there is an oval space of about 10 square miles, in which the coal averages 5 feet, but, in the surrounding area, the thickness decreases, the coal becomes impure and carbonaceous shale replaces it. On the southern slope of the Black Hills, a coal bed, 5 feet thick near Edgemont, is distinctly local; it quickly disappears toward the southeast, giving place to sandstone; while toward the northwest, it becomes merely a coaly shale. There is little coal on the easterly side of the Black Hills, only thin lenses of coal and coaly shale were seen, and these are confined to the northerly portion. The thick bed near Aladdin has a bone parting somewhat more than one foot thick, which, in appearance, closely resembles cannel; it has 38.69 per cent. of ash. The upper part of the Lakota holds much petrified wood; cycad stems are numerous at several localities.

Darton recognized his Cloverly formation on both sides of the Bighorn Mountains in north central Wyoming, where, in much of the region, the Dakota sandstone appears to be wanting. Streaks of coal were seen occasionally in the Lakota, but they offer no promise of economical importance. Fisher<sup>118</sup> saw Lakota coal in the drainage area of No Wood creek at the westerly base of Bighorn Mountain. It is less than 50 feet above the Morrison formation and is found within a considerable area. One opening was in a bed divided by a parting of 2 inches into benches, each 4 feet; but the coal is a lens and thins away rapidly on all sides. The coal is dark with dull earthy luster, conchoidal fracture and resembles carbonaceous shale; but it is bituminous coal with not more than 11 per cent. of ash. Fisher suggested that the formation might be Dawson's Kootenai. No coal was seen by Woodruff within the southwestern part of the Bighorn Basin and the formation appears, according to Darton, to be barren in central western Wyoming, but

<sup>118</sup> C. A. Fisher, Bull. 225, 1904, pp. 355, 362.

coal, too thin to be worked, was found by Washburne in the north-east part of the Bighorn Basin near the Montana line.<sup>119</sup>

Calvert reports that, in the Electric coal field, Park County, Montana, the Kootenai is 577 feet thick and with same general structure as that of the Cloverly. The Fuson, 230 feet, consists of variegated shales, limestones and thin sandstones; the Lakota, 249 feet, has a coal bed, one foot thick and underlying a conglomerate sandstone; but it seems to be local. In the Livingston coal field of the same county, the Kootenai is 540 feet thick and apparently has no coal. In the Crazy Mountains coal field of Meagher County, north from Park, Stone found the Kootenai only 235 feet thick with variegated sandstones in the upper half and variegated shales in the lower half. The lowest of the sandstones is coarse and has layers of conglomerate; it overlies one foot of black shale; no coal is reported.<sup>120</sup>

Calvert<sup>121</sup> found 512 feet of Kootenai in the Lewistown coal field of Fergus County, where the upper part is variegated shale with two massive, cross-bedded sandstones, 8 and 25 feet thick; the lower part, 147 feet, is coarse sandstone, locally conglomerate, with sandy shale. The workable coals of the Kootenai in this field are in the lower portion at 60 to 90 feet above the base and underlie a massive cross-bedded sandstone. In some districts only one seam is present but in others there are several. The seams are distinctly lenses, separated by unproductive spaces. The thickness seldom exceeds 5 feet and ordinarily the coal is divided into benches by partings of shale or bone. The roof is shale or sandstone and the floor is shale or clay; in many cases a bench-bone is at top or bottom of the coal. A dull, lusterless coal, resembling cannel, was seen at several places but especially in the Mace mine, where it occurs as lenses within the coal, the largest being 200 feet long. The coal is accepted as bituminous, but the percentage of ash varies greatly.

The Great Falls coal field in northern Cascade County, west

<sup>119</sup> E. G. Woodruff, *Bull.* 341, p. 203; C. W. Washburne, the same, p. 170; N. H. Darton, *Bull. Geol. Soc. Amer.*, Vol. 19, pp. 447-449.

<sup>120</sup> W. R. Calvert, *Bull.* 471-E, pp. 34, 53, 58; R. W. Stone, *Bull.* 341, p. 80.

<sup>121</sup> W. R. Calvert, *Bull.* 341, pp. 110, 113, 117, 119; *Bull.* 390, pp. 56, 61, 72, 74.

from Fergus and north from Meagher, was examined by Weed and afterward by Fisher.<sup>122</sup> The Kootenai, 400 to 500 feet, according to Fisher but about 750 according to Weed, was formerly regarded as Dakota; but J. S. Newberry in 1887, cited by Weed, determined that it is Kootenai. The Dakota was not recognized. The individual deposits are inconstant, sandstones and shales alike being lenses. The coal horizon is about 60 feet from the base and the seams are clearly lenses. Weed has described the coals in detail. The great coal seam, with extreme thickness of 12 feet in Sand Coulee district, splits toward the west into two beds, which, where last seen, were separated by 25 feet of shale. The seams are usually divided and the benches often differ in quality of the coal, coking and non-coking being found within the same bed. Picked samples from one bed had barely 10 per cent. of ash, but one from the middle part of the bed had 27 per cent. Official samples, collected by Fisher, give from 16 to 23 per cent. of ash. As in sampling of the coal, nothing is taken which ought to be removed in mining, it is certain that this fuel, as it reaches the consumer, must be decidedly inferior in quality.

Stebinger<sup>123</sup> gives about 2,000 feet as the thickness of Kootenai in the Teton coal field, which, like the Great Falls field, is near the western boundary of Cretaceous deposition in Montana. The formation is practically without coal, there being only some black shale with 6 or 8 inches of coal.

The Kootenai shows great variation in thickness within Alberta. Dowling,<sup>124</sup> summarizing observations made by himself and others in various parts of the province, states that the maximum deposition was near the axis of the Rocky Mountains, where the base is a great bed of sandstone, succeeded by sandstones and shales with many seams of coal. In the Elk River escarpment, it is 3,600 feet, but at Blairmore, toward the east, it is but 750; northward, near Banff, it is 3,900 feet, but in Moose Mountain, east from the main range, it is only 375 feet. Farther east, the formation is unim-

<sup>122</sup> W. H. Weed, *Bull. Geol. Soc. Amer.*, Vol. 3, 1892, pp. 302, 303, 313-321; C. A. Fisher, *Bull.* 356, 1909, pp. 22, 50, 51, 52, 77, 78.

<sup>123</sup> E. Stebinger, *Bull.* 621-K, 1916, p. 124.

<sup>124</sup> D. B. Dowling, *Geol. Survey Memoir*, 53, 1914, p. 27.

portant owing to thinning of the beds; it has not been recognized in Manitoba.

In Alberta, the Kootenai is fully exposed only in the more disturbed portion of the Rocky Mountains area and the more important coal deposits, for the most part, are west from the Mountains in British Columbia. Mackenzie<sup>125</sup> measured about 700 feet of Kootenai on Oldman river in southern Alberta, in the Foothills region. The rocks mostly arenaceous. An overlying sandstone formation was assigned to the Dakota. A Coal Measures group, about 200 feet thick, is in the upper part of the Kootenai, where the sandstones increase in coarseness. Near Blairmore, five coal seams were examined; the total is about 40 feet, but two of the beds are poor and shaly; elsewhere the quantity of coal is less.

The Crowsnest coal field<sup>126</sup> is farther west, in and beyond the Mountains, and the greater part is in British Columbia. In Crowsnest pass, within Alberta, McEvoy gives a section of 4,736 feet, which he regarded as wholly Kootenai. The coal bearing portion begins at 1,170 feet from the base and is 1,847 feet. The coal is 198 feet, somewhat less than in the main field farther west. McLearn<sup>127</sup> states that the lower part of the Kootenai in this region contains abundant remains of plants and erect stems of trees.

Dowling<sup>128</sup> examined a small area of Kootenai on the North Saskatchewan river, about the 55th degree and near the 118th meridian. There, behind the Brazeau Hills, he saw 5 coal seams within a vertical distance of 631 feet. The lowest and highest, with somewhat more than 12 feet thickness, yield worthless coal, but the second and third, with about 23 feet of coal, are good, though the ash is rather high, being from 12 to 15 per cent.: the grade is semi-bituminous.

Malloch<sup>129</sup> reported upon an extensive district farther west, on the headwaters of the Saskatchewan, Bighorn and Brazeau Rivers, and within the outlying ridges of the Rocky Mountains. The thickness of Kootenai is 3,658 feet, which is unexpectedly great, as

<sup>125</sup> J. D. Mackenzie, *Summ. Rep. Geol. Survey, Canada*, pp. 239, 243, 244.

<sup>126</sup> J. McEvoy, *Ann. Rep.*, Vol. XIII., 1900, Pt. A, pp. 84-88.

<sup>127</sup> F. H. McLearn, *Summ. Rep.*, 1915, p. 111.

<sup>128</sup> D. B. Dowling, *Summ. Rep. for 1913*, pp. 150, 151.

<sup>129</sup> G. S. Malloch, *Memoir 9-2*, 1911, pp. 25, 31-33, 52, 53, 59, 60.

farther south in the foothills the formation is thin. In the basal 700 feet, there is a ripple-marked sandstone as well as shales and sandstones with impressions of rain drops. Sandstones and shales are irregular throughout and clear evidence of contemporaneous erosion was observed at several localities. Some thin beds of conglomerate were seen but they are indefinite and are clearly local.

Twenty-one coal seams were seen in a section of 2,760 feet, from 2 inches to 9 feet thick; in another section of about 1,100 feet in the upper part of the formation, 7 seams were seen, with total thickness of about 26 feet, while in a third of nearly 1,300 feet, there are 8 seams with total thickness of more than 52 feet, besides other seams less than 3 feet thick. Comparison of the sections make clear that the seams are lenticular. The coal throughout is bituminous and, with rare exceptions, is coking. The quality is excellent, ash and sulphur being low.

Malloch thinks that the shales, sandstones and conglomerates are of fluvial origin. Absence of roots in the floor of coal seams leads him to suggest that these may have developed in bogs within choked oxbows or on coastal plains. The quantity of coal decreases rapidly eastward from the mountains.

#### SOME CHEMICAL FEATURES OF CRETACEOUS COALS.

No substance resembling the pyropissite of Sachsen has been mentioned by any observer, the only allied material being that seen by Dunker in the Hannover region, which he thought might be hatchettin. Resin of one sort or another occurs commonly; it is termed Bernstein, retinite, walchovite or simply resin by various authors. It is in grains or in lumps several inches long in the Lower Quader coals of Bohemia and Moravia; at one locality in Hungary it is so abundant as to give the local name to a coal seam; there is much in New Zealand; in North America, resins are characteristic features of coals in the Laramie, the Fox Hills and the Pierre as well as in those of the Benton. The color is from honey yellow to dark yellow and according to Thiessen is rather darker in the Fox Hills coals of northern Colorado than in the Eocene coals of the Dakotas. Resins appear to be wanting in bituminous coals of

high grade; at least, no note is made anywhere respecting their existence in such coals.

Cannel has been reported from numerous places. Often it evidently is little more than highly carbonaceous mud, forming a faux-toit, faux-mur, or a thick parting, which may be regarded as roof and floor to the benches which it separates; but typical cannel is by no means rare. A great cannel lens was seen by Hector and by Campbell in one portion of the Buller coal field in New Zealand and Denniston has referred to what are clearly localized cannel deposits in coal beds. Hector has given the proximate analysis of the lens as water, 6.20; ash, 3.60; volatile matter, 61.41; fixed carbon, 38.58. Within the United States and western Canada, cannel has been described from Laramie, Benton and Kootenai horizons.

Cannel was discovered in the Benton of the Colob field, Utah, by Richardson, whose description shows that it is the lower bench of at least two lenses occurring at the same horizon. The material was studied microscopically by D. White, who recognized it as a typical cannel. At a later date it was studied in detail by Thiesen,<sup>130</sup> who reported that it has the appearance and characteristics of cannel. Under medium enlargement, the coal is a dark, homogeneous mass, in which are embedded resinous particles, dark and light, with some large spore exines and cuticles, this embedded material comprising about one half of the whole. Under higher power, the enclosing material is shown to be like the "groundmass" of other coals, being in largest part a mass of closely packed very thin flattened particles, most of which are spore and pollen exines, with small fragments of cuticles. In great proportion, these are fragmentary and many are so macerated that they are unrecognizable; but even in this condition, the color and optical action are the same as in the recognized cuticles and exines. As all intergradations are present, he thinks it reasonable to conclude that the origin is the same. With this is the amorphous substance or binding material as in the débris of lignite. The darker resinous substances are the more abundant and, in color as well as in appearance, they resemble those of lignite. Many are cylindrical, having retained the shape of resin cells in the wood. Smaller particles enter into the

<sup>130</sup> R. Thiessen, "Origin of Coal," 1914, pp. 244, 245.

groundmass. The darker resins are deep brown in color and in general are opaquely glassy. The lighter resins are in striking contrast and tend to be more irregular in form. Besides charred cell fragments, few other bodies are present and none of them is in recognizable condition. In variety of constituents, this coal is very simple and thus approaches Paleozoic cannel very closely. It is so brittle that proper sections cannot be prepared. The analysis showed 67.61 of volatile matter and 32.39 per cent. of fixed carbon in the pure coal. The cannel is overlain by a thin bituminous bench, which has 60 per cent. of volatile to 40 of fixed carbon, making probable that the upper bench contains much spore material.

Cannel is said to be present in the Lakota sandstone of the Black Hills, at a Kootenai horizon, where it is in two benches, each about a foot and a half thick and overlain by bituminous coal. The proximate analysis suggests that this is more probably a bony coal, as the volatile is but 38.64 and the fixed carbon 61.46 per cent. in the pure coal; the ash is 24.16. Cannel is present in the Kootenai of the Elk River district of Alberta, the composition being 65.55 of volatile and 34.45 of fixed carbon; the ash is only 9.86 per cent.<sup>131</sup>

That coals of very different types may occur in the same vertical section is evident from conditions in the Wealden of Hannover. Dunker<sup>132</sup> states that in many localities the coal resembles the older black coals, there being no trace of woody structure and the streak is blackish brown. This type of coal was analyzed by Regnault; but lignite is present also, which preserves the woody structure and has reddish brown streak. A sample from Helmstadt was analyzed by Varrentrapp. The results are:

	C.	H.	O and N.
I.....	89.50	4.83	4.67
II.....	73.50	5.18	21.30

Beside these there is the Blätterkohle, composed of leaves and twigs of conifers and cycads, which is so little changed that the leaves become flexible when soaked in water. This type occurs in the same

<sup>131</sup> U. S. Bureau of Mines, Bull. 22, 1913, p. 194; D. B. Dowling, Geol. Survey of Canada, Memoir 53, 1914, p. 74.

<sup>132</sup> W. Dunker, "Monographie," etc., p. xiii.

vertical section with other coals, some of which are of the "black" type. No analysis of the Blätterkohle is given. Dunker conceives that the black coal was formed from lycopods and ferns, as no remains of other plants have been found in it; the lignite, however, seems to him to be composed of conifers, cycads, lycopods and ferns. The ash of the Wealden coals in Hannover, according to analyses made by Saurwein and published by Zincken,<sup>133</sup> appears to average high, for in most cases the percentage exceeds 13.

Czjžek<sup>134</sup> has described the black coal with black brown streak mined near Grünbach in Lower Austria, which occasionally contains fragments of branches, retaining their form but showing no trace of fiber. This, belonging to the Upper Cretaceous, is a lignitic coal, for, as analyzed by Schrotter, it has carbon, 74.84; hydrogen, 4.60; oxygen, 20.56. The water and ash are very low. The important coals of Hungarian Cretaceous are in the middle or fresh-water formation consisting of marls and coal beds. Hantken presents no detailed analyses; the water and ash, for the most part, are less than 10 per cent.

The Cretaceous coals of Queensland are rarely thick enough to be workable; they occur as lenses scattered over a great area. The analyses reported by Jack<sup>135</sup> are all proximate; reduced to pure coal for fixed carbon and volatile they show:

	Water.	Ash.	Volatile.	Fixed Carbon.
I.....	7.16	36.53	37.22	62.77
II.....	8.25	19.02	41.82	58.17
III.....	0.33	30.20	43.37	56.62
IV.....	2.32	9.65	17.26	82.73
V.....	8.30	2.80	42.26	57.73

The coal of No. V., belonging in the Lower Cretaceous, cokes well. The stratigraphic relations give no explanation for the low volatile of No. IV. There is no relation between ash and volatile, for the ash of III. is almost ten times that of V., but the volatile is almost the same in both coals.

<sup>133</sup> C. Zincken, "Ergänzungen zu der Physiographie der Braunkohle," Halle, 1871, pp. 4, 5.

<sup>134</sup> *Jahrb. k. k. Reichsanst.*, Vol. II., Part 1, p. 144.

<sup>135</sup> R. L. Jack, "Geology of Queensland," pp. 398, 532, 537.

The analyses of New Zealand coals are proximate. Hector has published those of samples taken from different parts of two important seams:

	Water.	Ash.	Volatile.	Fixed Carbon.
I.....	13.93	7.16	46.85	53.15
II.....	16.46	7.20	33.45	66.54
III.....	4.98	1.19	41.89	58.10
IV.....	10.38	0.98	38.36	61.63

The difference in volatile of I. and II., from the same bed, is unusually great. Cox has given the results of numerous analyses of coals from the Buller field; the coal is bituminous and that from some mines is caking. The water content is very low, seldom exceeding 7 per cent. The ash is amazingly small, there being less than one per cent. in 9 of the 14 samples and only 4 exceed two per cent. Analyses of coals from Otago, as reported by Hutton, have in most cases very little ash. One cannot resist the suggestion that the samples may have been selected "average" lumps.<sup>136</sup>

Many thousands of analyses of coals have been made by the United States Bureau of Mines and a great number have been made for the Geological Survey of Canada. The samples consist of cuts across the whole bed, omitting such partings or benches as should be removed before shipment of fuel from the mine. For the most part, the samples have been taken from mines in successful operation or, if the region be undeveloped, from such seams as gave promise. The purpose of the sampling is to determine the commercial value of the property and the method is beyond doubt the best yet devised. But the student of geological relations should read the descriptive portion of Bulletin 22 in order to learn how far the analyses concern matters occupying his attention.

The Laramie coals. The Laramie formation, as defined in preceding pages, contains at most localities only thin seams of coal; but in the northern part of the San Juan Basin of New Mexico and Colorado as well as in the Edmonton region of Alberta, the

<sup>136</sup> J. Hector, *New Zealand Reps. for 1871-2*, pp. 132, 134; J. H. Cox, the same, for 1874-6, p. 25; F. W. Hutton, "Geology of Otago," 1875, pp. 101, 105, 110.

seams become thick and of economic importance. Two analyses of the great Carbonero seam have been published, I. near Fruitland, where the seam consists of bone, shale and coal, 12 feet, and at base 5 feet of coal, which was sampled; II. near Pendleton, where the thickness is 48 feet, but only 7 feet were included in the sample.

	Water.	Ash.	Volatile.	Fixed Carbon.	Sulphur.
I.....	9.89	10.19	48.10	51.90	0.80
II.....	8.30	8.25	42.61	57.39	0.80

The Edmonton coals are subbituminous and break up on exposure; but this disintegration is much less rapid if the fuel be stored under cover. Dowling has reported the results of numerous analyses, which show no serious variation in composition of the pure coal; it suffices to cite three from the upper group, which includes the great seam on Pembina River, and one from the Clover Bar group several hundred feet lower in the section.

	Water.	Ash.	Volatile.	Fixed Carbon.
I.....	12.93	10.00	41.46	58.52
II.....	13.78	6.86	40.33	59.66
III.....	11.78	3.31	45.58	54.42
IV.....	17.28	7.30	47.30	52.70

Coals of the Clover Bar group appear to be less advanced in conversion than those of the higher group; three samples from different mines yielded 43, 45 and 47 per cent. of volatile. The ash rarely exceeds 8 per cent.<sup>137</sup>

The Fox Hills coals. The coals taken by the writer to be of Fox Hills age are irregular but they are better than those of the Laramie, within the United States; and in some extensive areas they are of great economic importance. Along the eastern base of the Front ranges, these coals are mined on large scale in several fields from New Mexico almost to the Colorado-Wyoming line; in much of the region the seams are broken more or less by bony partings, but these are separated readily and they have not been included in the samples taken for analysis. Of the analyses, Numbers I. to V. are

<sup>137</sup> U. S. Bureau of Mines, Bull. 22, p. 141; D. B. Dowling, Memoir 53, pp. 11, 18, 21, 47.

from the Raton-Trinidad field; VI. and VII. are from the Canyon City field; VIII. and IX. from the Boulder District; and X. is from Platteville, about 40 miles north from Denver.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 3294...	2.72	14.57	38.51	61.49	0.83	84.58	5.54	7.64	1.41
II. 3295...	3.45	16.67	40.14	59.86	0.91	83.62	5.77	9.06	1.55
III. 6595...	2.45	17.40	34.36	65.64	0.96	85.32	5.67	6.93	1.12
IV. 115D...	2.25	20.44	38.15	61.85	0.82	84.08	5.61	8.02	1.47
V. 7196...	3.88	13.73	33.18	66.82	0.57	84.56	5.34	7.97	1.56
VI. 6254...	9.89	6.21	42.05	57.95	0.52	76.30	4.77	17.33	1.08
VII. 6376...	5.44	12.10	46.12	52.88	0.87	77.67	5.96	14.18	1.32
VIII. 1523...	18.68	5.99	46.30	53.70	0.73	76.28	5.30	16.16	1.53
IX. 6836...	17.32	4.64	41.06	58.94	0.39	74.97	5.18	18.00	1.46
X. 6408...	28.90	5.02	43.63	56.37	0.70	73.19	5.19	19.51	1.41

The ash is high at the south, but the seams in the lower part of the Vermejo group yield a fuel so good for steaming purposes that the high ash becomes unimportant; the ash decreases northwardly and in the Boulder District it is about that of an ordinary good coal. But in the same direction the type of coal changes; in the Raton-Trinidad field, one finds usually a high-grade bituminous coal, that from some extensive mines yielding a strong coke; in the Canyon City field, the coal is still bituminous, but it does not cake and the oxygen is about double that in the Trinidad coals; in the Boulder District, the coal is distinctly subbituminous, is xyloid in appearance and disintegrates on exposure. There are no such violent contrasts between proximate and ultimate composition, such as have been recognized in some of the newer coals.

The Fox Hills as a coal-bearing formation is important in southwestern Wyoming; the Adaville seam of Uinta County has maximum thickness of 84 feet; at least a part of the Black Buttes coal group in Sweetwater County belongs here; the coal assigned to the Lewis in Carbon County is taken by the writer to be at a Fox Hills horizon. The seams become thin and unimportant eastwardly. The Adaville seam yields coal of almost the same composition at two widely separated mines, which differs little from that of the Boulder District in Colorado. The volatile in the coals of Uinta and Sweetwater Counties varies from 38 to almost 49 per cent., though in the coals compared the carbon is almost the same throughout. The

lowest percentage of carbon in either county is barely 73; usually it is somewhat more than 76 per cent. These coals are high in water but not in ash. They are classed as subbituminous and are not held in high esteem as better fuel from the Pierre is readily accessible.<sup>138</sup>

The Pierre coals. These attain great importance in the San Juan, Uinta and Green River Basins as well as in portions of Alberta in Canada. There are few localities whence coal, positively recognized as Lower Pierre, has been taken for official analysis. Probably the Hagan coal of Sandoval County in New Mexico belongs here, but the only available analysis is proximate. The Upper Pierre or the Lewis and the Bearpaw shales have no coal deserving consideration. The Middle Pierre or Mesaverde, as originally defined, is the productive formation. Its coals are mined in the Cerillos coal field, where all grades from bituminous to anthracite are obtained; and in various parts of the San Juan Basin. Of the analyses given here, I. and II. are from the Cerillos field, III. and IV. are from the southern part of the San Juan Basin, V., VI. and VII. are from the northern part.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 6153.....	5.70	5.99	2.47	97.53	0.78	93.84	1.99	1.96	1.34
II. 6154.....	3.76	4.89	37.07	62.83	0.62	82.49	5.78	9.86	1.25
III. 1307.....	10.79	18.66	47.94	52.06	1.79	78.06	5.70	13.10	1.35
IV. 1278.....	12.29	6.99	42.84	57.16	0.78	78.43	5.51	14.00	1.28
V. 5761.....	1.71	6.92	39.68	60.32	0.71	82.50	5.50	9.58	1.71
VI. 2121.....	3.04	9.66	44.70	55.30	4.03	81.01	5.99	7.27	1.70
VII. 537D.....	1.24	16.12	38.30	61.70	0.66	84.64	5.56	7.49	1.65

The sample III. consisted of slack and VII. represented the run-of-mine. II. and VII. yield a high grade coke. The anthracite of Cerillos is believed to be due to a sheet of andesite overlying the seam.

The Mesaverde coals of the Uinta Basin are in two groups, separated by a thick sandstone. The upper group, the Paonia shales, has many coal beds of which one or more may be workable at a given locality; the lower group, Bowie shale, contains important seams. In the southeastern part of this basin, the Paonia and Bowie cannot

<sup>138</sup> Bull. 22, pp. 137, 138, 69, 58, 59, 54, 55, 82 for Colorado-New Mexico; pp. 310, 319 for Wyoming.

be distinguished; yet in the western part the coals differ altogether. The Paonia coals are subbituminous, with 15 to about 20 per cent. of water, almost 17 of oxygen and less than 76 of carbon; whereas the Bowie coals have less than 4 per cent. of water, 9 to 12 per cent. of oxygen and from 79 to 83 per cent. of carbon. The Paonia coals are at times rather high in ash, but the coal mined from the Bowie is uniformly clean, the ash rarely exceeding 6 per cent.

The Mesaverde coals are important in Sweetwater County of Wyoming, within the Green River Basin. There, as in the Grand Mesa area within the Uinta Basin, the coals are in two groups, Almond and Rock Springs, which are separated by a greater interval than the Paonia and the Bowie. The Almond coals are lower in water than are those of the Paonia, but the oxygen is higher while the carbon is from 72 to 76 per cent. The Rock Springs coals have about 5 per cent. less of oxygen and the carbon varies little from 79 per cent. Farther north in Wyoming, within the Bighorn Basin, a coal is mined near Cody which has 21 per cent. of oxygen and only 71 of carbon.<sup>139</sup>

In Montana, the coal seams are more irregular than in southern areas, the lenses, for the most, are of less extent and the coal is apt to be dirty. The Judith River seams, or approximately the Upper Mesaverde, are of subbituminous coal with water from 10 to 25 per cent., 16 to 20 per cent. of oxygen and 72, 73 to 76 per cent. of carbon. But the coals of the Eagle sandstone are bituminous with 12 to 16 of oxygen and 76 to 80 per cent. of carbon. The ash usually is high, 13 to more than 16 per cent.

Dowling has published many analyses of Belly Rivers coals from Alberta. They are proximate but they represent a great number of localities. The water rarely exceeds 5 per cent. in the Foothills region but in the Lethbridge-Medicine Hat region it increases eastwardly and, near Medicine Hat, it is about 20 per cent. The ash in beds of workable thickness is low, seldom exceeding 8 per cent. According to two analyses of Lethbridge coal, published by Stebinger,<sup>140</sup> that fuel is on the borderland between subbituminous and

<sup>139</sup> U. S. Bureau of Mines, Bull. 22, pp. 67, 140, 141 for San Juan Basin; pp. 55, 56 for Uinta Basin; pp. 313, 315, 316 for Green River Basin.

<sup>140</sup> E. Stebinger, Bull. 621-K, 1914, p. 138.

bituminous, but it is of better quality in respect of ash than the Montana coals at the same horizon.

*The Benton Coals.*—The published reports contain no reference to occurrence of coal in deposits representing the Niobrara time interval; the coal seams are associated with rocks containing Benton fossils. These coals are confined to the western part of the Cretaceous area within Arizona and Utah, though extending eastwardly for a short distance into New Mexico, Colorado and Wyoming. The coal in Arizona and New Mexico is rather high in ash, about 14 to 16 per cent., and the sulphur seems to be not far from 2 per cent., so that it is an inferior fuel. Analyses I., II. and III. are from Iron County, Utah, where the coal seams are often closely associated with marine limestones; IV. is from Emery County, where the coal is mined extensively; V. and VI. are from Uinta County, on the northwest side of the Uinta Basin.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 5494....	4.93	13.04	45.40	54.60	8.19	76.82	5.56	8.29	1.14
II. 5304....	10.35	9.82	45.39	54.61	7.27	76.52	4.97	10.05	1.19
III. 5305....	14.19	9.92	44.00	56.00	7.10	72.83	4.77	14.18	1.12
IV. 12627....	4.00	5.93	45.4	54.6	0.44	81.01	5.64	11.52	1.39
V. 5510....	8.82	6.25	43.10	56.90	1.95	76.67	5.58	14.52	1.19
VI. 5513....	8.21	11.79	42.87	57.13	2.20	76.28	5.60	14.70	1.22

The carbon is highest at the west in Iron County, being more than 83 per cent. in the pure coal of I.; it is 78 in the pure coal of III., 81 in that of II. and 81 in the best coal from the Emery coal field. The sulphur in Iron County is so abundant as to suggest contribution by animals. V. and VI. are the upper and lower benches of a single bed and show improved conditions during formation of the upper bench. Lee has given analyses of the upper and lower benches of a bed in Delta County of Colorado; the upper bench has 6 per cent. and the lower bench 22 per cent. of ash. There, as in the Uinta County seam, the lower bench, though richer in ash, is poorer in volatile. The Frontier coals in Uinta County of Wyoming, in the Green River Basin, have excellent fuel in several of the seams. They are bituminous, low in ash and sulphur and have from 77 to almost 81 per cent. of carbon.<sup>141</sup>

<sup>141</sup> Bureau of Mines, Bull. 22, pp. 47, 139; for Utah, pp. 80, 193, 194; C. T. Lupton, Bull. 628, p. 80; W. T. Lee, Bull. 510, p. 201.

The coals of Dakota age are insignificant. The only ultimate analysis shows that in one case, at least, the coal is high-grade bituminous but with notable percentage of ash.

The Kootenai is without coal south from the northern border of Wyoming and there as well as in Montana the coal is not of high grade. In the Black Hills of Wyoming one finds extensive mines at or near Aladdin. In one of those the water is from 14 to 18, the ash from about 5 to 16 and the sulphur from 5 to 7 per cent., all in freshly mined coal. Within Montana, the Kootenai coals become important locally and are mined at many places in Cascade and Fergus Counties. In the former county, the water is but 3.5 to 7.5 per cent. but the ash is from 14 to 21. Sulphur is less than 3 per cent. The coal is bituminous, the carbon in pure coal being about 80 and the oxygen, barely 15 per cent. In Fergus County, the ash within several districts is from 10 to 17 per cent. of the air-dried coal; but only 3 out of 10 samples gave more than 10; the sulphur, however, is much greater than in Cascade, being 5 per cent. and upward. The percentage of carbon in pure coal is from 80 to 85 and that of oxygen 9 to 15. But one analysis shows only 75 of carbon with 19 of oxygen.<sup>142</sup>

The analyses published by Dowling<sup>143</sup> show regional variation in the coals of Alberta. The ash is highest in areas near the mountains, where three districts have 13 to 22, 10 to 20 and 8 to 17 per cent. In all other areas, it rarely exceeds 8 and is usually about 5. The water is about 3 per cent. Sulphur is in small quantity, there being one extensive region with barely a half per cent. The coal is bituminous and often is caking. Anthracite is obtained in disturbed districts.

In reading the results of analysis as given above, one is in danger of concluding that "clean" coal is the rule and "dirty" coal the exception. Emphasis must be laid on the fact that samples for analysis have been cut, for the most part, from mines in successful operation or from promising exposures. Lenses yield the best coal in the central portions; toward the borders, their coal becomes dirty and usually passes into carbonaceous shale. In many vertical sec-

<sup>142</sup> Bull. 22, pp. 305, 126, 127, 130-133.

<sup>143</sup> D. B. Dowling, Memoir 53, pp. 74-79.

tions, one observes that a large proportion of the seams are "dirty," and in reading descriptive notes of seams from which samples were taken, he finds that only in rare instances is a seam, upwards of 3 feet thick, clean throughout, while of thicker seams, a half or more must be rejected in sampling. Even in thinner seams, selection of samples requires no little skill. The testimony of observers, cited in preceding pages, proves that a very great part of the Cretaceous coal was formed amid conditions unfavorable to accumulation of clean coal. Generally speaking, foreign materials are in partings, but occasionally the mineral matter is distributed throughout so that it cannot be removed by washing.

#### SUMMARY.

The facts recorded in preceding pages may be grouped to make clear their bearing upon the matters at issue.

1. *The Distribution of Coal.*—One who reads reports covering an extensive area is liable to believe that caprice has determined the distribution of coal. The presence of coal at one locality gives no assurance that it will be found at the same horizon in others, for great barren spaces exist between productive areas, so that individual seams appear to have small areal extent; apparently, the total area on which coal was accumulating at any time was a comparatively insignificant part of the whole. There is, however, an evident relation between occurrence of coal seams and the prevailing character of the sediments, which would justify the assertion that in one locality coal may be present, and that in another it is almost certain to be absent. The descriptions seem to prove that coal seams accumulate only under conditions such as mark great river or coastal plains, where intervals of relatively rapid subsidence were followed by others, during which subsidence was slow; finer materials were deposited upon the coarser and coal accumulation began. But where the deposits are fine, such as those laid down at a notable distance from the source of materials and under a practically constant cover of water, coal is not present.

The relations are sufficiently clear in the Upper Cretaceous of Europe. Coal is of rare occurrence in England, France and western Germany, where the deposits, almost without exception, are

marine and largely calcareous; but in a part of France, the closing stages are characterized by thick fresh-water deposits and thin seams of lignitic coal have been observed. Land deposits abound in eastern Germany and there coals are found, which at times attain economic<sup>144</sup> importance. The Hastings Sand of England, at base of the Wealden, is thought to be a delta deposit; if so, the areas remaining may mark, in greatest part, the submerged portions, as they contain no coal and the sand holds much driftwood. This formation has been recognized in France, where within small areas, some coal seams exist which have been mined. The Wealden is exposed within a large space in Hannover, reaching westward from the Harz Mountains to the Holland border, where it underruns newer formations. At this western limit, the deposits are fine clays or marls with important limestones, but no coal. Coarse deposits are reached farther east and with them the coal. The seams are usually thin and irregular, but occasionally one is more than 5 feet thick. In a section, toward the west, where shale, more or less argillaceous, predominates, a workable seam occurs, but it is associated with the principal sandstone of the section. The coals of New Zealand and Queensland either rest on sandstone or are separated from it by thin clay or shale.

The immense area of Cretaceous in the United States and Canada affords ample opportunity for comparisons. Each formation, with possible exception of the Niobrara, is coal-bearing. The chief source of detritus was at the west, though important contributions were received from the southern border, which probably lay in northern Mexico, not far from the international boundary.

The Laramie marks the closing stages of the Cretaceous and, where the succession is complete, deposition appears to have been continuous into the Eocene. Except in a portion of Alberta, where a brackish-water fauna is found, the rocks are of continental type; leaves abound in many beds and the animal remains are of river or pond forms. The conditions recall those observed on the great

<sup>144</sup> It should be noted that this term, "economic importance," has not the same signification everywhere: in the United States, a coal seam, less than thirty inches thick, is not thought to be workable, except in localities without railway communication. On the continent of Europe seams very much thinner have been worked.

plains of China. The drainage appears to have been irregular and shifting, the deposits are variable in form and composition, and except in a few localities, widely separated, the coal seams are thin. The periods, during which coal accumulation was possible in any locality, were usually brief; but in the northern part of the San Juan Basin, one seam attains the thickness of 100 feet and in the Edmonton district of Alberta the seams are not only thick but, unlike the seam in the San Juan, they yield coal of excellent quality.

The Fox Hills, underlying the fresh-water Laramie, is recognizable as a persistent sandstone with intercalated shales and coal seams. It resembles a low-lying strand of vast extent, frequently invaded for considerable periods by the sea, so that it has an off-shore fauna, which is of strangely persistent type. This is passage from the continental conditions of the Laramie to the marine conditions of the Pierre. The coal seams, yielding better fuel than that from the Laramie seams, are thin and variable at most localities, but at times in considerable areas, some of them become thick and of great economic importance. Merely insignificant seams occur in the San Juan Basin except at the north, where two, 4 and 12 feet thick, are present in the shales immediately overlying the Pictured Cliffs sandstone. In the Green River Basin, the Adaville seam has a maximum thickness of 84 feet, but the seams become thin eastwardly and there are great spaces in which the formation seems to be barren. In central and eastern Wyoming as well as in Montana and Alberta, only occasional exposures of coal have been reported and those are unimportant. In the basins along the eastern foot of the Front Ranges in New Mexico, the seams are numerous and some horizons are extremely productive along this line of more than 300 miles; but the individual seams are variable to the last degree in thickness and quality, there being many spaces where the coal is either wanting or worthless.

The Pierre at the west and southwest is, for the most part, a mass of sandstone and sandy shale; toward the east, it becomes shale at top and bottom, while Middle Pierre or Mesaverde persists as a wedge of sandstone and shale thinning eastwardly until it becomes replaced wholly with fine shales and irregular limestones. This wedge thins away unbroken in Colorado and New Mexico but

in Montana it is divided by shales into subordinate wedges, and these "fingers" disappear toward the east, giving place to marine shales. Coal seams are confined to the areas of sandstone and shale, there being none in the fine-grained marine shales, which extend from the longitude of central Colorado to the eastern border of the Cretaceous, except in the sandy strip along the southern border in New Mexico. In the sandstone wedges, land and marine conditions alternated, the former continuing for long periods at many localities, long enough to permit accumulation of thick coal seams. At the same time, the distribution of coal is indefinite. In the southern basin within New Mexico, the coal seams are important locally, but they are irregular and there are broad spaces, which are altogether barren. The story is similar in the Uinta Basin; coal seams are very numerous in the Mesaverde, but they are not persistent; portions of the column showing workable seams in one district are apparently without trace of coal in others. The features are the same in the Green River Basin; an extensive coal field in Sweetwater County of Wyoming has many lenses yielding coal of excellent quality, but at the same horizons in other counties there is either no coal or the seams are mere streaks. Farther east, the sandstones thin away and all traces of coal disappear. Elsewhere in Wyoming the distribution of coal is certainly capricious; here and there one finds a seam thick enough to be dug for local supply, but such exposures are separated by intervals of many miles. In Montana, coal occurs only in scattered spots, while the intervening spaces seem to be barren. Seams of workable coal are more numerous in Alberta and the lenses are larger; conditions favorable to coal accumulation existed in a large area. But there, as in the United States, the sandy coal-bearing formation thinned away toward the east and was replaced with shale, in which no coal is known.

The sandy deposits, containing Benton coals, reach only to the 109th meridian, aside from an isolated deposit in Colorado near the 108th. The most westerly localities at which coal has been found are in southwestern Utah, where the conditions are not in accord with the assertion that coal is present only in association with prevalingly coarse materials. In those fragmentary fields, the rocks

are, in very large part, clays, clay shales and limestones, the last serving occasionally as roof or floor to coal seams. The area must have embraced not less than 2,000 square miles and its surface must have been a broad mud flat during formation of the coal seams. It was little above the sea-level. At 50 miles farther east, the conditions are wholly different, for there the coals are associated with sandy deposits, as they are farther north. The relations appear to give support to Gilbert's suggestion, offered more than 40 years ago, that the Wasatch Mountains were the source whence the sediments were derived. In that case, the conditions would be normal, for the sluggish streams, carrying only fine materials, would build up merely a mud flood plain, such as one sees at localities along the Atlantic coast, on which peat deposits are accumulating. The deposits are largely sandstone in northeastern Arizona, where they contain 3 coal seams near the base. Benton rocks in the southern part of the San Juan Basin have about 66 per cent. of sandstone and have 3 coal seams; but the sandstone decreases northwardly and the coal disappears. The condition is similar in the northern or main portion of the basin.

The Ferron sandstone of Castle Valley, Utah, at eastern base of the Wasatch Mountains, contains many and irregular coal seams, of which some are locally important; but these are confined to the southern part of the valley, where the sandstone is several hundred feet thick; no trace of them remains in the northern portion, where the sandstone has become thin. The Frontier sandstone contains several seams, yielding excellent coal, in Uinta County of Wyoming, but farther east the sandstone becomes thin and the coal disappears. The Bear River formation, of fresh-water origin, has numerous coal seams but it thins away rapidly toward the east.

The Kootenai has no coal in the southern portions, the first appearance being in the Black Hills region of northeastern Wyoming; there and in the Bighorn Basin of the same state the rocks are chiefly sandstone and contain patches of coal, which are sources for local supply; but they are far apart in Wyoming as well as in Montana, there being coal in only an insignificant part of the exposed area. In Alberta and the adjacent portion of British Columbia, the individual seams cover greater areas than in any part of the

United States and the quantity of coal in some fields is enormous, there being 198 feet in the Alberta section of the Crowsnest field. But the formation thins eastwardly and it has not been recognized in Manitoba.

The distribution of coal in the several formations of the Cretaceous is wholly similar to that of peat deposits on coastal plains.

*2. Structure and Other Characteristics of the Accompanying Rocks.*—Information respecting these topics is lacking for many districts but details given by observers in many others are all in accord and are sufficient.

The Wealden sandstones of England contain driftwood and often have rippled surfaces; the shales have sun cracks, while limestone slabs, in many cases, are rippled and are marked by trails. Stems of trees, replaced with silica or oxide of iron, abound in the rocks between coal seams. Grains of coal are in Wealden sandstones of Westphalia. The Upper Cretaceous of Borneo and Queensland has grains of coal in the sandstones. In Queensland, sun cracks, worm burrows and trails are notable features of the sandstones, which are cross-bedded at many places. Fragments of tree stems, usually silicified, characterize the sandstones of Queensland, New Zealand and Greenland.

Many observers report that the Laramie deposits in Colorado and Wyoming are extremely irregular, sandstones and shales being lenses. In Montana, the sandstones assigned to this formation are often cross-bedded, rippled and contain fossil wood. The Fox Hills sandstones are much cross-bedded in parts of Colorado and Montana. Fossil wood is reported from one locality in southern Colorado, where cross-bedding is not uncommon.

The Pierre sandstones show cross-bedded layers in the Cerillos field, where some of the beds are locally conglomeratic. Cross-bedded and rippled sandstones are in the southwestern part of the San Juan Basin, and petrified stumps and logs abound at at least one locality on the eastern border of the basin. In the Grand Mesa portion of the Uinta Basin, the sandstones and shales are so irregular in distribution that many times sections, separated by only a short interval, are unlike; cross-bedding in sandstones was observed frequently. Within Montana, the sandstones of Electric and Liv-

ingston fields are much cross-bedded, while in Cleveland and Big Sandy fields, rippled surfaces were observed and the shales and sandstones are in rude lenses. So also in the Milk River field where all deposits are lens-like and the sandstones are cross-bedded. In Teton County, the Two-Medicine formation is characterized by great irregularity of the deposits and fossil wood abounds; the Virgelle (Lower Eagle) sandstone is coarse and cross-bedded. The conditions in Alberta are similar; the Belly River sandstones have been described as cross-bedded, rippled and marked by trails; the same features were observed farther north on Pine River.

The Benton in New Mexico, has, near the base, the Tres Hermanos sandstone, cross-bedded, rippled and locally conglomeratic, which persists to the northeastern corner of the San Juan Basin. Similar features are recorded in the southwestern part of that basin as well as from localities in the Uinta Basin. The Dakota is usually more or less cross-bedded and holds local conglomerates. The Kootenai of New Mexico is cross-bedded and locally conglomeratic; it is rippled, cross-bedded, locally conglomeratic in the Black Hills, where petrified wood, chiefly cycads, is abundant. The conditions are similar in Montana, while in Alberta the same features were observed at many localities.

These features, characterizing the rocks of the several formations, indicate deposition in, at most, shallow water, as well as subsequent exposure to subaërial conditions. The rippling and cross-bedding were due to water movements in probably most cases, but it is possible that there has been too great readiness to accept this mode of origin as almost universally applicable. The writer has observed the ripple marks in rocks of several formations and has compared them with wind ripples seen by him in the sandy areas in the western states and in Russia and Prussia, as well as on broad river benches. The resemblance to fossil ripples, seen in many beds, is so great that the mode of origin must be the same for both. It may be also that some of the "cross-bedding" was due to wind action. The complex structure shown in many diagrams is precisely that of the æolian limestone of Bermuda and observable more or less distinctly in many dunes; the "current bedding" is clearly due to stream action. The presence of tree stumps and logs is evidence

of shallow water and suggests the action of floods, which dropped their load on the broad surface, which was exposed during the intervals between floods.

3. *The Form of Coal Deposits.*—Cretaceous coal seams are lenses. No statement to this effect occurs in any of the older works, as nearly all students, prior to less than 25 years ago, held in a somewhat hazy way, that coal seams are continuous deposits. Comparison of sections in all fields proves that this conception was erroneous. The Wealden coals of Hannover are local, present in one section, absent in others, and in all cases they have small areal extent. There is a rather persistent coal horizon at the base, which seems to be made up of overlapping lenses. The Lower Quader has only nests of coal, which occasionally become workable; the Hungarian coals are well-defined lenses as are those of Queensland; and the detailed studies in New Zealand have proved lens form in the great seams.

The condition in North America is so marked that it has been noted by the great majority of observers during later years. Occasionally, a seam has an area so extensive that the describer is unwilling to commit himself as to the form. But it must be remembered that, even though the lenses have an area of hundreds or thousands of square miles, the general features are the same with those of smaller lenses, united by transgression to form the large one.

The Laramie coals are in lenses, usually small and thin within the United States; the great bed of the Saskatchewan in Alberta becomes only a thin deposit of carbonaceous shale in its southern extension. The Fox Hills seams are lenses, usually thin or impure, but locally important and workable in considerable areas. This feature is noteworthy in all districts along the eastern base of the Front Ranges in New Mexico, as well as the southern tier of counties of Wyoming. The Middle Pierre (Mesaverde) is probably the most productive formation with usually one or more workable seams; but its seams are like those of the newer formations. They are variable and uncertain in New Mexico; in the Uinta Basin, west from Grand River, portions of the section, containing workable coals in one district, are wholly barren in others; east from that river the coals are local, important here, unimportant or absent else-

where; the Mesaverde coals of Green River Basin attain commercial importance in only one county; in Montana the lenses are usually small and thin; in Alberta, the coals are present in a great area, and often workable, but available details merely suggest, they do not prove that the seams are lenses.

Benton coals are present in only a small part of the Cretaceous area, but, wherever they have been studied, the lens form is characteristic. In southwestern Utah, in Castle Valley of that state, in Gunnison Valley of Colorado and in Uinta County of Wyoming, they are distinctly lenticular. The Dakota coals are merely insignificant lenses. The Kootenai is without coal south from northern Wyoming. There, within the Black Hills districts, coal lenses of typical form are present but they are all small, nowhere embracing more than a score of square miles. An occasional lens has been found in the Bighorn Basin. The lenses are few and unimportant in southwestern Montana; they become numerous and some attain workable thickness in Lewistown and Great Falls fields; but in Teton County, on the northern border, there are only insignificant nests. In Alberta, on the contrary, as well as in the adjacent part of British Columbia, the seams are numerous and the quantity of coal is enormous. Comparison of sections leaves no room for doubt respecting the lenticular form of the seams.

The lenses ordinarily show increase of foreign matters toward the borders, the coal is broken by fine partings and very often it becomes at last merely carbonaceous shale with laminæ of coal. Sometimes the lenses are connected by a stretch of black shale, but commonly no such bond exists and a barren space intervenes. These lenses, great and small, are similar to peat deposits on broad river plains and even more strikingly to those on coastal plains; at times, these are separated by broad spaces, forested; at others they are united by carbonaceous muds, while at still others, the peat of several lenses has become continuous by transgression.

4. *Contemporaneous Erosion.*—The effects of contemporaneous erosion are conspicuous. The curious intermingling of coal and débris, observed at one locality in the Loewenberg area of Silesia, seems to be explicable only by the supposition that it represents a washed out swamp. The presence of coal grains in sandstone may

signify that a coal seam in process of formation was exposed. Local conglomerates in many sandstones occupy the channelways of rapid streams; local unconformities between sandstone and shale suggest changes in direction of drainage. The coal seams themselves appear to have been subjected to subaërial erosion and to have been traversed by streams as in modern swamps. "Horsebacks" or "rolls" of the roof have been found wherever extensive mining operations have been carried on. They mark channel ways of varying width and depth, now filled with material like that of an overlying deposit; sometimes the material is the same with that forming the immediate roof, in which case the stream was probably contemporaneous with the bog; but not infrequently the channelway was excavated after the roof had been deposited. The conditions are commonplaces in modern deposits.

5. *Soils of Vegetation*.—Reports on areas of Cretaceous coal in North America give few instances where soils of vegetation have been observed in the rocks between coal seams. One must not forget, in this connection, that, generally speaking, observers have been compelled to depend on natural exposures, which are imperfect, and that the work has been done at cost of much personal discomfort. But the few illustrations available show that the condition is less rare than the record shows. A dense growth of *Sphenopteris*, in place, has been reported from the Wealden of England and a similar growth of *Equisetum* from that of Hannover. A grove of large trees exists in the Upper Cretaceous of Queensland, clearly in place of growth, where they were buried by drifting sand; an ancient soil in New Zealand contains roots in place. The Upper Cretaceous of Greenland has bands with ferns, conifers, dicotyledons, erect stumps and silicified wood. An old soil was seen on Pine River of Alberta in the Lower Kootenai, which contains erect stems, evidently in the place of growth.

6. *The Roof of Coal Beds*.—Coal seams may have shale, clay, sandstone or limestone as the roof. In parts of some mines one finds shale as roof in one part, but sandstone in others; the variation being due, apparently, to local removal of the shale during or prior to deposition of the sandstone. It may be marine limestone or a detrital deposit containing marine fossils. Occasionally, a parting

of marine limestone serves as roof to one bench and as floor to the other. These limestones are thin but they are proof of submergence, due perhaps to change in course of drainage or to the breaking away of a barrier, which protected the swamp from sea-invasion, a by no means rare phenomenon on the New England coast. The roof is apt to be irregular.

7. *The Coal Seams*.—Where succession is undisturbed and deposition appears to have been continuous, the roof material ordinarily becomes more and more carbonaceous at the base and passes gradually into bone or into impure coal, with normal structure, a faux-toit. But the transition is abrupt in many cases where no evidence of disturbance by erosion is apparent; a condition which leads to the suggestion that a suddenly increased influx of mud or fine sand ended the bog's existence. In such cases the contact between coal and roof is irregular, defining the bog surface.

Accumulation of vegetable material was rarely continuous during long periods, though there are seams several feet thick, which are said to be unbroken by partings of any sort. Commonly, however, coal seams are divided into benches by partings of mineral charcoal, clay, sand or limestone, which indicate longer or shorter periods of interruption. In many cases, this interruption was not complete and the parting consists of bone or bony coal, at times closely resembling cannel; but when the parting consists of inorganic matter, it is proof of at least local cessation. The thickness of partings usually varies within narrow limits, but in some cases it is so great as to attract the attention of even a casual observer. Čzjžek notes the thinning away of a considerable interval and the consequent union of two important seams, with increased thickness of coal. In the Denver Basin, one parting increases from a mere film to 25 feet within a few miles; the partings in the Carbonero seam of the San Juan Basin thicken in one direction, so that the great bed, 100 feet thick, becomes three, with thicknesses of 7, 30 and 15 feet respectively, in a vertical space of 200 feet. Taff describes a parting, which increases from zero to 16 feet within 2,000 feet, the exposures being complete in one mine. The Trinidad seam, 11 feet thick near Trinidad, Colorado, becomes 58 feet within 3 miles by thickening of the partings. Lee has given details making almost certain that

7 coal seams, wholly distinct and separated by thick intervals, unite within 4 miles into one, 42 feet thick. Partings contain fossils; in southwestern Utah, Lee saw a limestone parting with brackish-water forms; at another locality a seam with marine limestone as roof and floor has a parting with fresh-water fossils. Clay partings frequently have remains of plants.

Benches of coal beds seams often differ so much as to make certain that conditions were not the same during the several periods of accumulation. One bench may yield caking, and another may consist of non-caking coal; in one, the ash may be unimportant while another may be so dirty as to be worthless; one may thin away to disappearance while others overlap it. Details respecting the benches are given only for districts where mining operations are on large scale, but enough is known to justify the old method of regarding benches as separate coal seams.

In a general way, Cretaceous coals vary from massive to laminated, the latter with alternating bright and dull laminæ—and these types are found throughout the whole section. Ordinarily, woody structure is not apparent to the naked eye, but it is distinct in many places. The Upper Cretaceous coal of Silesia is xyloid; a seam of Moorkohle is near Mährens-Trubau; the coal of the Boulder District is almost as xyloid as the Eocene coals of the Dakotas; it contains logs, carbonized, jetified or silicified. Most of the Wealden coal in Hannover is black and apparently without woody structure, but in the same section with the black coal one finds lignitic brown coal and even Blätterkohle, the latter being an accumulation of leaves and not related to the Blätterkohle of the lower Rhine region.

Few notes are available respecting microscopic structure of Cretaceous coals. v. Gümbel<sup>145</sup> studied only jet from Raschwitz in Silesia and coal from the Wealden of Hannover. Woody structure is well-preserved in the former; the latter contains numerous remains of leaves with clumps of wood cells and bark parenchyma, all easily recognized. Thiessen<sup>146</sup> examined coal from the Denver Basin, probably Fox Hills. So close is the resemblance to that

<sup>145</sup> C. W. v. Gümbel, *Sitzb. bay. Akad. Wiss.*, 1883, Math.-Phys. Kl. I., pp. 157, 160.

<sup>146</sup> R. Thiessen, "The Origin of Coal," pp. 241-245.

from the Eocene of Montana and Dakota that he believes the general conditions during accumulation were similar. Woody parts are more compressed in the older coal, but the canals of wood fibers are well shown and appear to be filled with resin. Resins form a large part of the mass, while spores and pollen exines compose not more than 5 to 10 per cent.; the "fundamental matrix" or binding material is derived, as in lignite, from cellulosic substances; all gradations are present from fibers to a homogeneous mass. The fibers are mostly xylum elements of plants, but whether of trees, shrubs or herbs is not always determinable.

8. *The Floor of Coal Seams.*—The floor may be clay, sandy or clayey shale, sandstone or limestone. Occasionally the transition from coal to floor seems to be abrupt, but in most cases there is a faux-mur. Even where this seems to be wanting, the basal part of the coal is, in most cases, higher in ash than that above; frequently the faux-mur is bone and occasionally it resembles the "coarse coal" of the Carboniferous. Limestone floors have been reported only from southwestern Utah, where they contain marine fossils. Bulging floors have been reported from many localities. They are due in some instances to irregularity of the surface on which the coal accumulated; in the Boulder District, petty swales were numerous, in which accumulation began and afterward crossed the low divides—after the manner so familiar in recent peat deposits. But "rolls" in the floor often mark the courses of streams crossing the swamp in its earlier stages.

American reports contain few references to the presence of roots in the floor; two notes have been given for the Trinidad-Raton area and D. White recognized characteristic underclays with roots in the Boulder District. But the scantiness of references in detailed reports indicates merely that the reporter did not look for the roots; Lesquereux,<sup>147</sup> long ago, asserted that most of the underclays are full of roots or rootlets. He visited exposures in the Raton Mountains, Canyon City, Golden, Marshall in Colorado and Black Buttes in Wyoming; at most localities, he found the shale containing such abundance of roots that these seemed to be a compact mass.

<sup>147</sup> L. Lesquereux, "On Formation of the Lignite Beds of the Rocky Mountains," *Amer. Journ. Sci.*, Vol. VII., 1874, p. 30.

The presence of roots in the floor is apparently the ordinary condition in much of Europe. Rzehak<sup>148</sup> says that the Wealden coals of Hannover are distinctly autochthonous, there being root-stocks in most of the underclays. Grand' Eury<sup>149</sup> states that he had found roots in the floor of Cretaceous coal at many places. At la Liguise and les Gardies in the Causses there are many roots in place under the seam mined there. The Middle Cretaceous at St. Paulet shows roots in the marly mur of some coal seams; these he says are in place for some of them cross leaves of dicotyledons lying flat in the rock. In his later paper, he reports that, at Sarladais, roots in the mur give rise to stems. Similar conditions were seen in the Upper Cretaceous at Valdonne.

9. *The Fauna*.—Fresh-water forms predominate in the Laramie, the Judith River, the Bear River and occur occasionally in other formations; but for the most part the Cretaceous fauna is marine. Discussion of the faunas as such has no place here, but reference to some features is necessary.

The Lower Colorado fauna is characteristic throughout the whole region from western Utah to the eastern border; it is present in the limestone roof and floor of coal seams as well as in the accompanying shales and in the coal-bearing sandstones of Utah. The Pierre fauna abounds in the fine shales and occasional limestones, but it abounds equally in the Middle Pierre (Mesaverde) sandstones of New Mexico, where it is found in profusion at several horizons. The fauna is practically the same, be the rock sandstone or shale. The depth of water in western Utah was not great, for coal beds are numerous, one of them having a parting with fresh-water mollusks, though the roof and floor are marine limestone. The character of the rock and the numerous coal seams make the condition equally clear for the Mesaverde of New Mexico. The marine faunas give no support to the opinion that deep-sea conditions existed anywhere, but they make probable that the body of water, covering at times the greatest part of the Cretaceous area, was a very shallow sea. Fineness of sediments, in general, may be taken as indicating distance from the source of supply.

<sup>148</sup> A. Rzehak, *Zeitsch. f. pr. Geologie*, Vol. XXII., 1914, p. 8.

<sup>149</sup> C. Grand' Eury, *Autun*, 1902, p. 127; *C. R.*, t. CXXXVIII., 1904, 669, 741.

10. *The Flora*.—The Cretaceous coals are usually so far advanced in conversion as to give little information respecting the plants by which they were formed. Knowledge of the flora of the period is derived from fragmentary material found in the rocks; that has been transported, it represents mostly the upland vegetation and tells nothing about the swamp plants. In the United States and Canada, the coals are often rich in resins, indicating that conifers entered largely into their composition; such wood as has been recognized seems to confirm this conclusion. Cycads were abundant locally during the Kootenai but conifers and dicotyledons were predominant during the Upper Cretaceous, when ferns and lycopods appear to have been subordinate. Memoirs on European coals, consulted by the writer, usually contain little information upon the subject. Wood, fully recognizable, is present in the Upper Cretaceous coal of the Loewenberg region, but in the Grünbach coal, no structure is shown, though the stems and branches retain their form. The Wealden of Hannover contains abundance of conifers, cycads, lycopods and ferns; the plant remains in coal must be distinct there. Dunker thinks that the "black coal" of that region was derived from lycopods and ferns, because they are the only forms found in it; the lignitic brown coal is largely of conifer origin, as the stems occurring in it resemble *Pinus*.

11. *Chemical Relations*.—Discussion of the chemical relations of Cretaceous coals must be deferred until the older coals have been studied; but it may be well to call attention to some matters.

Like the Tertiary coals and some peats, these coals are resinous in many districts. Cannel is present at several horizons, with all features which mark the sapropels or Lebtorfs of later times. The carbon content is higher than that of Tertiary coals, but progressive enrichment with increasing age is less marked. In the Fox Hills the extremes of carbon are 73 and 84; in the Pierre, 71 and 84; in the Benton, 77 and 83, and in the Kootenai, 75 and 85. No note has been taken here of metamorphosed coals; anthracite is present at several horizons. No ultimate analyses of the Laramie coal are available and there are very few of the Kootenai. The variations are small compared with those in the Tertiary. In the Cretaceous as in the Tertiary, not all accumulations of vegetable materials had

attained the same degree of enrichment before burial; the minimum of the Pierre rarely falls below 75, but there are seams with only 71 or 72. The condition is well marked in Hannover, where the "black coal" has 89 per cent. of carbon, the brown coal, 73, while the Blätterkohle is almost unchanged—the several types occurring in the same vertical section.